

March 1990

**SPAWNING AND ABUNDANCE OF FALL CHINOOK
SALMON (*ONCORHYNCHUS TSHAWYTSCHA*) IN THE
HANFORD REACH OF THE COLUMBIA RIVER, 1948-1988**



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D. D. Dauble
D. G. Watson

March 1990

Prepared for the U.S. Department of Energy
under Contract DE-AC06-76RL0 1830

Pacific Northwest Laboratory
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SPAWNING AND ABUNDANCE OF FALL
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OF THE COLUMBIA RIVER. 1948-1988

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Richland, Washington 99352

SUMMARY

Historically, fall chinook salmon spawned in the mainstem Columbia River from near The Dalles, Oregon, to the Pend Oreille River in Idaho, a distance of nearly 900 km. Today, however, the 90-km-long Hanford Reach of the Columbia is the only significant mainstem spawning habitat remaining for upriver bright (URB) stocks of fall chinook salmon. This report attempts to summarize factors influencing the abundance of fall chinook salmon in the Hanford Reach from 1948 to present. The review also identifies research needed for effective management of this valuable resource.

Aerial counts of chinook salmon redds have been conducted since 1948 at Hanford to provide an index of relative abundance among spawning areas and years. The counts also have been useful to document the onset of spawning and determine intervals of peak spawning activity. Spawning for fall chinook salmon in the Hanford Reach usually has extended from mid-October to the third week in November. Time of first-observed spawning ranged from September 28 to October 26 with a median date of October 16. The median date for peak spawning, or the date of the highest total redd count, was November 11. Estimated numbers of visible redds ranged from a low of 65 in 1955 to a high of 8630 in 1987. Redd counts from the Vernita Bar and Upper Locke Island areas averaged 33% and 25% of the total, respectively, for the 41 years of record. Fall chinook salmon spawned at temperatures (daily average ranging from 12.0 to 18.5 °C). Weekly mean temperatures during peak spawning averaged 12.5 °C. Weekly average flows during peak spawning ranged from 1244 to 3276 m³/s (44,000 to 116,000 ft³/s) and averaged 2203 m³/s (78,000 ft³/s) from 1948 to 1988.

In aerial counts, the primary physical factors influencing the ability to observe redds included depth of water over the redds and clarity of the water. Wind action, available light, orientation of the river, and direction of the current also influenced redd counts. Field measurements suggest that the upper depth limit for detecting redds during aerial surveys conducted in 1988 was 3-4 m. Other studies indicate that fall chinook salmon spawn at depths ranging to about 8 m. Thus, a large, but unknown proportion, of redds in deeper water are not detected during aerial surveys.

Returns of adult fall chinook salmon to the Hanford Reach have increased dramatically in recent years. The increase in number of spawners reflects, in part, continued supplementation efforts at the Priest Rapids Hatchery. The relative contribution of URB stocks to fall chinook salmon runs in the Columbia River increased from about 24% of the total in the early 1980s to

50-60% of the total. The relative contribution of URB to the commercial, tribal, and sport fisheries has also increased since 1980.

A number of factors affect the abundance of fall chinook salmon in the Hanford Reach. For example, increased variability in river flow during spawning, incubation, and hatching has created major changes in environmental conditions over the last 40 years. Juvenile and adult passage at hydroelectric dams and harvest management practices also affect the number of fish returning to the Hanford Reach to spawn. Also, hatchery production has supplemented wild run production since the early 1960s, resulting in increases in the number of fall chinook salmon in recent years. Juvenile and adult passage at hydroelectric dams and harvest management practices also affect the number of fish returning to the Hanford Reach to spawn.

The status of fall chinook populations needs to be monitored because present and planned activities could have a major impact on their survival in the Columbia River. Research needs for effective management of fall chinook salmon production in the Hanford Reach include efforts to:

- improve methods for documenting the location and extent of spawning areas
- characterize habitat requirements, and determine production potential
- evaluate current supplementation programs
- maintain flow policies, and design them to protect all life stages of fall chinook salmon
- ensure adequate protection of the Hanford Reach against future development.

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We appreciate the thorough reviews conducted by C. Dale Becker of Pacific Northwest Laboratory (PNL) and Mike B. Dell of Grant County Public Utility District in Ephrata, Washington. George Swan (National Marine Fisheries Service, Pasco, Washington) and Mike Dell also provided reports and data from personal files. William Rickard, Robert Gray, and Richard Jaquish provided additional support. Georganne O'Connor of PNL provided editorial assistance.

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1.0 INTRODUCTION

The Hanford Reach of the Columbia River provides the only major spawning habitat for the upriver bright (URB) race of fall chinook salmon (Oncorhynchus tshawytscha) in the mainstem Columbia River. These salmon are important to sport, tribal, and commercial fisheries because of their abundance and because they retain color and high oil content throughout their upstream spawning migration. Fall chinook salmon migrate upstream to spawning areas in the Hanford Reach from mid-August through October; they dig redds and deposit eggs from late October to late November. Embryonic development occurs in the gravel over the winter, and fry emerge in March through May. Fish rear in the main river and backwater areas for a short period before migrating seaward in late June and July (Becker 1973; Page et al. 1982).

Hanford Site biologists have conducted aerial surveys of spawning salmon in the Hanford Reach since 1948. The objective of early surveys was to determine if effluents from plutonium production reactors on the U.S. Department of Energy's (DOE) Hanford Site affected the abundance or distribution of fall chinook salmon. The DOE has continued to fund redd surveys even though the last production reactor was shut down in 1971. The annual surveys provide a continuous data base or index of abundance for 41 years of redd counts for fall chinook salmon. In addition, recent studies by public utilities, state and federal fisheries management agencies, and Indian tribes have extended the knowledge of fall chinook salmon populations in the Hanford Reach.

This report summarizes data on fall chinook salmon spawning in the Hanford Reach and presents a discussion of factors that may affect population trends. Most data are limited to fisheries agency reports and other working documents. Earlier reports by Watson (1970, 1976) provided information on fall chinook salmon spawning from 1947 to 1975. Information on anadromous salmonids associated with the Hanford Reach was summarized by Becker (1985). However, fisheries management practices in the Columbia River system have changed rapidly over the last decade, particularly under requirements of the Pacific Northwest Power Planning and Conservation Act of 1980 (CRFC 1981). New information has been generated and included in this report.

2.0 BACKGROUND

This section describes the study area and reviews migration and genetic characteristics of fall chinook salmon that affect their management and abundance. Also described is how historical development activities have influenced present distribution of fall chinook salmon in the Columbia River.

2.1 STUDY AREA

The Hanford Reach, a 90-km segment of the Columbia River extending from the upper end of McNary Dam Reservoir (near the downstream border of the Hanford Site) to Priest Rapids Dam, remains essentially free-flowing (Figure 2.1). Flows through the Hanford Reach are regulated by releases at Priest Rapids Dam (river km 639) and other upstream dams. Daily average discharges vary seasonally and range from about 1140 to 7070 m³/s (40,000 to 250,000 ft³/s). The Federal Energy Regulation Commission (FERC) has established minimum licensed flows of 1086 m³/s (36,000 ft³/s) at Priest Rapids Dam. Beginning with construction of Bonneville Dam in 1938 and ending with John Day Dam in 1967, 11 hydroelectric dams were constructed on the Columbia River (below the Canadian border) (Figure 2.1). These dams now block access or inundate most spawning sites used historically by fall chinook salmon in the mainstem Columbia River.

2.2 MIGRATION PATTERNS AND GENETIC CHARACTERISTICS

Fall-run chinook salmon are separated from other runs of chinook salmon primarily by their period of adult migration. Typically the fall race enters the lower Columbia River in late July and August. The Army Corps of Engineers includes all adult migrants counted after July 31 at Bonneville Dam, the first mainstem dam above the mouth of the Columbia River (river km 235), as fall run fish. Because run timing is later for fish passing dams further upstream, the date separating the summer and fall runs of chinook salmon becomes later as fish migrate upstream to Hanford. For example, all chinook salmon passing McNary Dam (river km 470) after August 8 and Priest Rapids Dam after August 13 are counted as fall-run fish. The major migration period for adult fall chinook salmon over McNary Dam has occurred during September (Figure 2.2). This interval coincides with a seasonal decline in maximum yearly water temperatures in the Hanford Reach (US DOE 1988). Peak of the migration over Ice Harbor and Priest Rapids dams was about one week later than McNary Dam because of the greater migration distance.

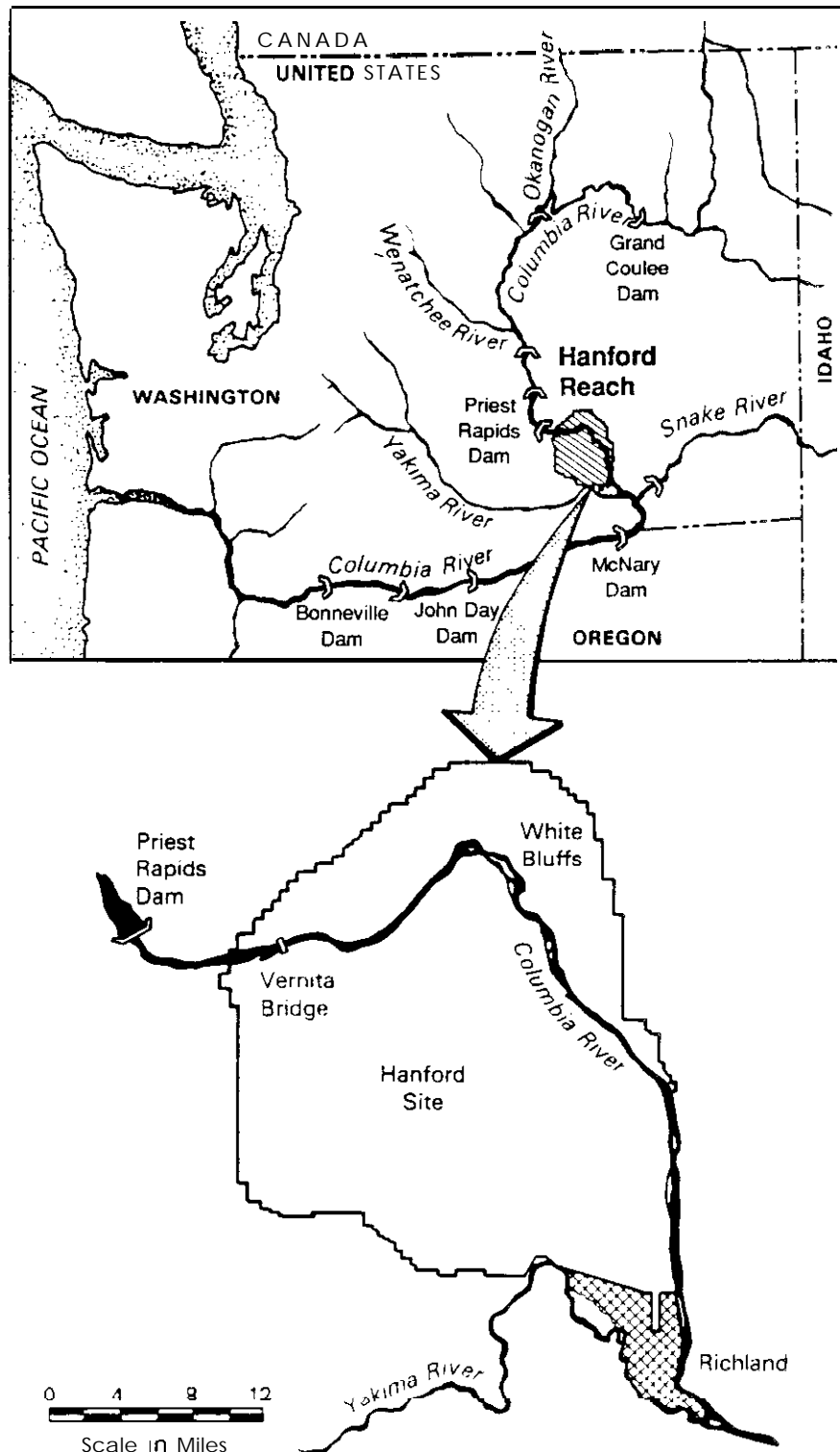


FIGURE 2.1. Location of the Study Area in Southeastern Washington State

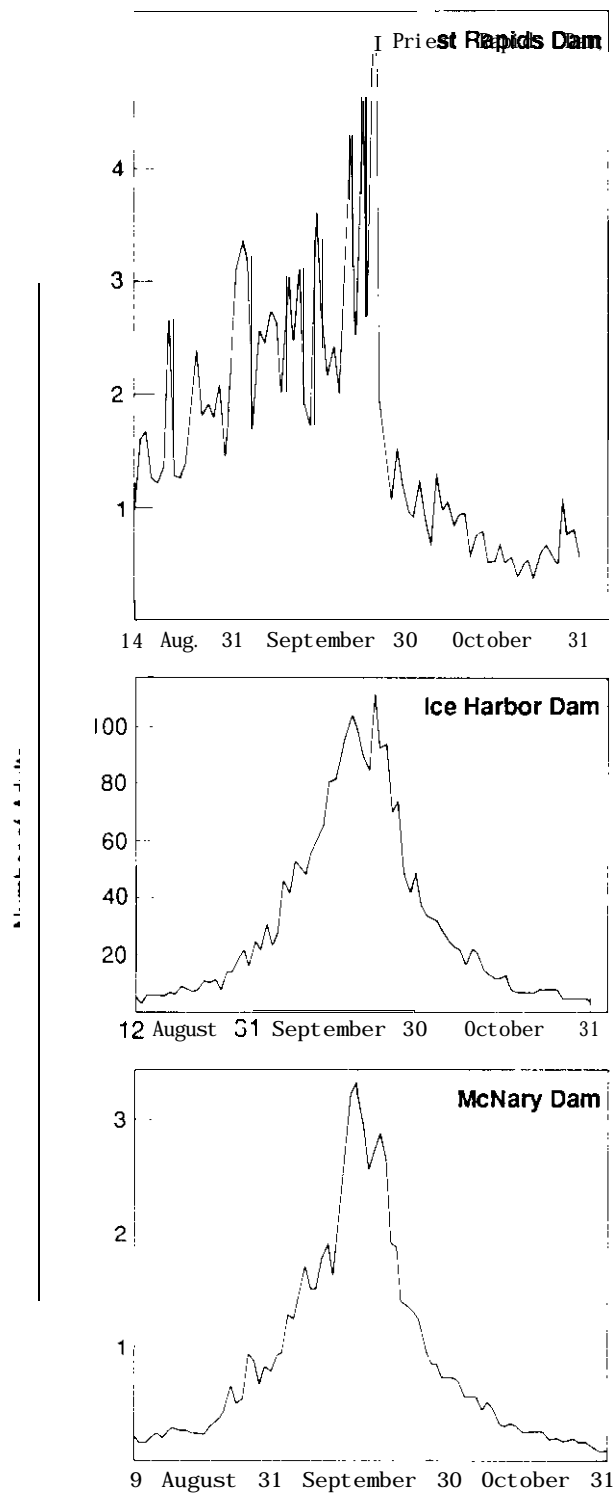


FIGURE 2.2. Run Timing for Fall Chinook Salmon Migrating Upstream past McNary, Ice Harbor, and Priest Rapids Dams, 1980 to 1988

The fall chinook salmon run entering the Columbia River is currently separated and managed by fisheries agencies as four stocks: upriver brights (URB), Bonneville Pool Hatchery stock (BPH), lower Columbia River Hatchery stock (CRH), and lower Columbia River Wild stock (CRW). The lower Columbia River stocks (wild and hatchery fish spawning below Bonneville Dam or in tributaries of the Bonneville pool) are usually designated as tules. The URB stock is primarily wild or naturally spawning and comprises populations originating from such tributaries are the Deschutes and Snake Rivers, and from the mid-Columbia River (primarily the Hanford Reach). The Hanford Reach is the only significant mainstem spawning habitat remaining for fall chinook salmon above Bonneville Dam.

The present population of URB fall chinook in the Columbia River is thought to be essentially genetically pure (Horner and Bjornn 1979). However, tule-type fall chinook salmon were periodically released from the Washington State Department of Fisheries rearing ponds at Ringold from 1963 to 1985 (M. B. Dell, Grant County P.U.D, personal communication). Fish production at the Priest Rapids Dam rearing facility has also been supplemented with eggs from the Bonneville Dam Hatchery. Adults from both the Ringold and Priest Rapids facilities return to spawn in the Hanford Reach along with their wild cohorts. Young (1980) and Young and Arthur (1982) estimated that 8% of the naturally spawning adult fall chinook salmon in the Vemita Bar area (river km 633) originated from the Priest Rapids Hatchery stock in 1979 and 27% in 1980. Thus, wild and hatchery stocks mix genetically when spawning in the Hanford Reach.

2.3 PAST AND PRESENT DISTRIBUTION OF FALL CHINOOK SALMON

Historically, fall chinook salmon spawned in the mainstem Columbia River from near The Dalles, Oregon (river km 308), upstream to the Fend Oreille and Kootenay rivers in Idaho (river km 1200, see Figure 2.3). Additional spawning areas were located in the lower Snake River (Fulton 196X). There may be some overlap with the earlier-spawning summer race of fall chinook salmon in the upper Columbia River drainage because of similar life history patterns. Current separation is based on run timing over dams (reviewed in Mullan 1987). Access of fall chinook salmon to the upper portion of the Columbia River drainage was blocked by Grand Coulee Dam at river km 959 in 1941 (Chapman 1943). Construction of McNary Dam in 1953 and John Day Dam in 1968 inundated about 200 km of additional mainstem spawning habitat (Van Hyning 1973). There is some evidence that construction of the Dalles Dam may have displaced spawners to upstream areas. Celilo Falls, which was almost impassable to adult salmonids during low flows,

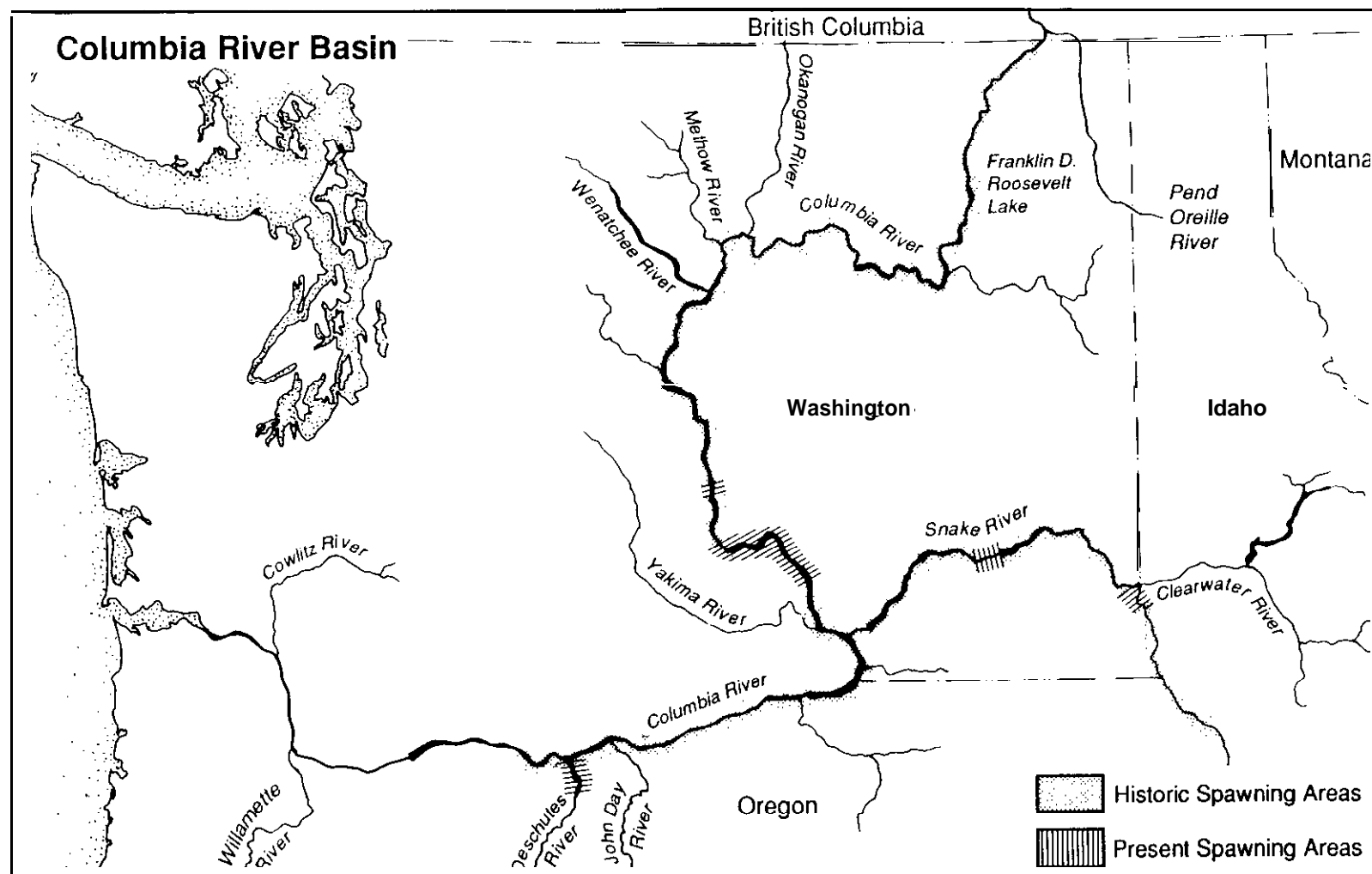


FIGURE 2.3. Comparison of Historical and Present-Day Spawning Sites for Fall Chinook Salmon in the Columbia River Drainage

was flooded out by The Dalles Dam in 1957. Removal of this potential barrier to upstream migration may have increased access of fall chinook salmon to additional upstream production areas (including the Hanford Reach) for spawning and rearing. For example, run size over McNary Dam averaged about 8600 adult fall chinook salmon for 1954 to 1957. This increased to about 62,000 adults per year for the three years following construction of The Dalles Dam. A listing of hydroelectric dams in the Columbia River and their construction dates, locations, and relative size is provided in Table 2.1.

Currently, most URB chinook salmon of natural origin come from the Hanford Reach. Minor spawning areas are located in the lower Deschutes and Yakima rivers. Some URB also spawn in the mainstem Columbia below Wanapum and Rock Island dams (Homer and Bjornn 1979). The URBs are also artificially produced at the Priest Rapids Hatchery and released below Priest Rapids Dam (river km 639) and sometimes farther downstream at the Ringold rearing facility (river km 577).

There is no evidence that spawning habitat limits fall chinook salmon production at current escapement levels to the Hanford Reach. However, less than half of all known spawning sites have been characterized. Optimal escapement values for the wild URB fall chinook salmon are currently being studied with Pacific Salmon Treaty funds (Norman 1987; De Vore 1989). Spawning habitat was not perceived as a limiting factor to fall chinook salmon production by

TABLE 2.1. Construction Timeline and Other Characteristics for Dams on the Mainstem Columbia River (Source: USACE 1975)

| <u>Project Name</u> | <u>Year Completed</u> | <u>River k m</u> | <u>Reservoir Length (km)</u> | <u>Active Storage (Acre ft)</u> |
|---------------------|-----------------------|------------------|------------------------------|---------------------------------|
| Bonneville | 1938 | 239 | 77 | 87,000 |
| The Dalles | 1957 | 309 | 39 | 53,000 |
| John Day | 1968 | 348 | 121 | 535,000 |
| McNary | 1953 | 470 | 95 | 185,000 |
| Priest Rapids | 1959 | 639 | 90 | 45,000 |
| Wanapum | 1963 | 668 | 29 | 161,000 |
| Rock Island | 1933 | 729 | 32 | 9,000 |
| Rocky Reach | 1961 | 763 | 68 | 36,000 |
| Wells | 1967 | 330 | 45 | 125,000 |
| Chief Joseph | 1955 | 877 | 82 | 115,000 |
| Grand Coulee | 1941 | 961 | 243 | 5,232,000 |

fisheries management agencies in 1982, given a spawning escapement goal of 40,000 adults above McNary Dam (TAC 1982). However, this assessment may need revision because current escapement to the Hanford Reach now approaches 100,000 adult spawners annually.

3.0 HANFORD REACH SPAWNING SURVEYS

This section describes fall chinook salmon redds were surveyed in the Hanford Reach, provides estimates of redd abundance by river location, and summarizes river temperatures and flows during spawning. Also discussed are how physical habitat variables influence distribution of redds in the Hanford Reach and factors that limit estimates of redd abundance.

3.1 SPAWNING SURVEY METHODS

Aerial counts of chinook salmon redds (spawning surveys) have been conducted annually at Hanford since 1948 from fixed-wing aircraft. One to seven surveys were flown each year at approximately weekly intervals over the spawning period from late September to November. Estimates of the number of redds were made at altitudes of 800 to 1200 ft (244 to 366 m) and at air speeds of 75 to 100 miles (120 to 161 km) per hour. When salmon redds were widely spaced, they were enumerated individually. When redds were close together or overlapped, they were estimated in units of 10 or 50. Two or more counts were made of areas of heavy spawning for each survey. Estimates of the number of redds were also compared between observers whenever possible. The angle of approach of the airplane was varied to obtain optimum visibility. Counts were usually obtained near mid-day with the sun at the observer's back, and polarized glasses were sometimes worn to reduce glare.

Aerial surveys are more effective in the Hanford Reach than in some other river systems because of the large size of the redds and the general clearness of the water. Average area of completed chinook salmon redds in the upper Hanford Reach was about 17 m² (Chapman et al. 1986), or about four times larger than redd sizes found in smaller rivers (Burner 1951). Secchi disc measurements (an indication of water clarity) at Priest Rapids Dam were consistently high and ranged from 3.0 to 4.5 m during October and November, 1976-1982 (Chapman et al. 1983).

Newly excavated redds appear from the air as light-colored, regularly shaped circular or oval areas that contrast with the normally darker periphyton-covered substrate. The redds remain visible for about 6 weeks before their surface becomes recolonized by algae growth. Thus, some redds counted at the beginning of the spawning period may not be visible by the end of spawning.

Redd counts in the Hanford Reach were made by D.G. Watson in all but 4 of 41 consecutive years of observation. Counts were made by R.F. Foster in 1947 and 1948, and by W.G. Hanson in 1957 and 1958. D.D. Dauble assisted with counts in 1987 and 1988. Because one observer made most of the estimates, year-to-year variation in counts was assumed to be

consistent with that observer's ability to estimate. However, estimates can be expected to vary between observers. For example, in one study of salmon spawning (where fish numbers were estimated in groups of 100 and 1000), a lack of precision between observers resulted in variances of +50% (Bevan 1961).

Aerial surveys provide a year-to-year index of relative abundance and variation in redd numbers. The estimates reported here are not absolute measures of the spawning population, because of highly variable conditions under which surveys must be conducted. Major variables that affect the accuracy of aerial surveys include river discharge, depth of spawning, cloud cover, and turbulence caused by winds (see Section 3.5).

Aerial surveys are useful to document the onset of spawning and to determine intervals of peak spawning activity. They also provide information on other qualitative aspects such as habitat selection and species interactions (Heggberget et al. 1986). Follow-up surveys with SCUBA (Swan et al. 1988) help delineate the boundaries of use in deeper water where redds are not visible from aircraft.

3.2 TIMING AND ABUNDANCE OF SALMON SPAWNING

Spawning for fall chinook salmon in the Hanford Reach usually extended from mid-October to the third week in November. Time of the first-observed spawning ranged from September 28 to October 26 with a median date of October 16 (N = 40). If initiation of spawning is taken as the interval where >5% of the peak count was first recorded, the median date would be about 1 week later, at October 24. We defined peak spawning as the date of the highest total redd count, and this ranged from October 26 to November 26 (N = 40). The median date for peak spawning was November 11. Peak spawning, as used here, does not represent the specific time of maximum redd construction because the redd count for each survey is a cumulative estimate of redds constructed prior to the survey date.

Counts of visible redds from 1948 to 1988 are summarized by designated spawning area in Table 3.1. Corresponding locations for the 10 designated areas are shown in Figure 3.1. Redds observed outside these 10 areas are included in the "other" column. Most of the "other" redds reported since 1980 were located at China Bar, a man-made shoal constructed near river km 628. The yearly redd total was calculated using peak counts from within each of the designated areas. The maximum count for an individual survey was not used because the date for peak spawning sometimes differed among spawning areas. This was mainly because of variations in conditions within and among the spawning surveys.

TABLE 3.1. Summary of Peak Redd Counts for 10 Designated Areas, 1948-1988

| Year | Number of Redds | | | | | | | | | | | Total |
|------|-----------------|--------|--------|--------|--------|--------|--------|--------|--------|---------|-------|-------|
| | Area 1 | Area 2 | Area 3 | Area 4 | Area 5 | Area 6 | Area 7 | Area 8 | Area 9 | Area 10 | Other | |
| 1948 | 120 | 330 | 0 | 38 | 69 | 83 | 90 | 2 | 0 | 53 | 2 | 787 |
| 1949 | 45 | 51 | 0 | 9 | 156 | 26 | 13 | 6 | 1 | 1 | 6 | 334 |
| 1950 | 24 | 35 | 0 | 36 | 74 | 58 | 14 | 9 | 3 | 44 | 0 | 315 |
| 1951 | 5 | 7 | 3 | 45 | 90 | 38 | 21 | 2 | 5 | 95 | 3 | 316 |
| 1952 | 73 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 23 | 40 | 3 | 539 |
| 1953 | 7 | 5 | 0 | 10 | 38 | 0 | 10 | 0 | 0 | 83 | 0 | 145 |
| 1954 | 4 | 12 | 0 | 8 | 83 | 44 | 1 | 0 | 7 | 6 | 0 | 167 |
| 1955 | 0 | 11 | 0 | 0 | 34 | 12 | 1 | 1 | 0 | 3 | 0 | 65 |
| 1956 | 0 | 3 | 0 | 7 | 40 | 17 | 0 | 6 | 0 | 17 | 0 | 94 |
| 1957 | 17 | 87 | 15 | 39 | 170 | 34 | 90 | 1 | 42 | 100 | 1 | 648 |
| 1958 | 32 | 87 | 100 | 99 | 223 | 45 | 64 | 48 | 130 | 176 | 2 | 1215 |
| 1959 | 1 | 0 | 0 | 36 | 60 | 40 | 1 | 0 | 32 | 111 | 0 | 281 |
| 1960 | 0 | 0 | 31 | 19 | 67 | 23 | 9 | 0 | 34 | 90 | 0 | 295 |
| 1961 | 0 | 15 | 12 | 49 | 86 | 46 | 7 | 4 | 23 | 640 | 0 | 940 |
| 1962 | 5 | 75 | 120 | 66 | 262 | 98 | 88 | 1 | 1 | 405 | 0 | 1260 |
| 1963 | 0 | 122 | 159 | 116 | 345 | 56 | 100 | 3 | 13 | 396 | 1 | 1318 |
| 1964 | 5 | 55 | 94 | 110 | 245 | 99 | 119 | 26 | 36 | 624 | 0 | 1511 |
| 1965 | 4 | 136 | 123 | 202 | 345 | 50 | 112 | 11 | 54 | 652 | 3 | 1778 |
| 1966 | 10 | 132 | 140 | 267 | 697 | 230 | 270 | 2 | 37 | 1300 | 0 | 3116 |
| 1967 | 34 | 205 | 160 | 248 | 499 | 155 | 455 | 28 | 17 | 1340 | 1 | 3343 |
| 1968 | 130 | 250 | 320 | 186 | 437 | 135 | 182 | 19 | 52 | 1500 | 5 | 3649 |
| 1969 | 252 | 401 | 410 | 427 | 903 | 126 | 362 | 30 | 50 | 1075 | 4 | 4322 |
| 1970 | 90 | 367 | 230 | 302 | 746 | 159 | 259 | 2 | 72 | 1486 | 9 | 3815 |
| 1971 | 183 | 374 | 180 | 386 | 740 | 72 | 230 | 24 | 10 | 1361 | 3 | 3601 |
| 1972 | 77 | 131 | 103 | 131 | 110 | 52 | 74 | 0 | 4 | 127 | 0 | 876 |
| 1973 | 121 | 330 | 123 | 170 | 722 | 176 | 283 | 29 | 59 | 882 | 5 | 3033 |
| 1974 | 76 | 113 | 28 | 49 | 86 | 47 | 67 | 0 | 4 | 153 | 3 | 728 |
| 1975 | 68 | 263 | 140 | 261 | 373 | 79 | 215 | 52 | 86 | 995 | 1 | 2683 |
| 1976 | 17 | 162 | 140 | 185 | 384 | 105 | 140 | 7 | 182 | 599 | 0 | 1951 |
| 1977 | 7 | 291 | 140 | 355 | 1136 | 161 | 263 | 8 | 47 | 760 | 0 | 3347 |
| 1978 | 18 | 156 | 60 | 326 | 789 | 74 | 386 | 73 | 145 | 975 | 0 | 3064 |
| 1979 | 66 | 229 | 145 | 297 | 672 | 172 | 257 | 42 | 92 | 980 | 0 | 2975 |
| 1980 | 29 | 112 | 32 | 64 | 194 | 33 | 119 | 0 | 35 | 856 | 0 | 1487 |
| 1981 | 82 | 222 | 190 | 270 | 1103 | 151 | 553 | 58 | 80 | 2120 | 0 | 4866 |
| 1982 | 7 | 149 | 210 | 278 | 1102 | 160 | 560 | 79 | 149 | 2060 | 12 | 4988 |
| 1983 | 24 | 284 | 200 | 511 | 1310 | 198 | 453 | 33 | 43 | 2216 | 0 | 5290 |
| 1984 | 88 | 514 | 190 | 1052 | 1920 | 85 | 853 | 87 | 55 | 2314 | 7 | 7342 |
| 1985 | 12 | 624 | 250 | 770 | 1949 | 370 | 863 | 152 | 107 | 2411 | 15 | 7645 |
| 1986 | 14 | 490 | 250 | 672 | 1810 | 370 | 1074 | 213 | 73 | 3082 | 22 | 8294 |
| 1987 | 251 | 780 | 320 | 900 | 1870 | 95 | 951 | 142 | 74 | 3150 | 27 | 8630 |
| 1988 | 264 | 715 | 330 | 828 | 1680 | 310 | 870 | 202 | 123 | 2742 | 48 | 8485 |

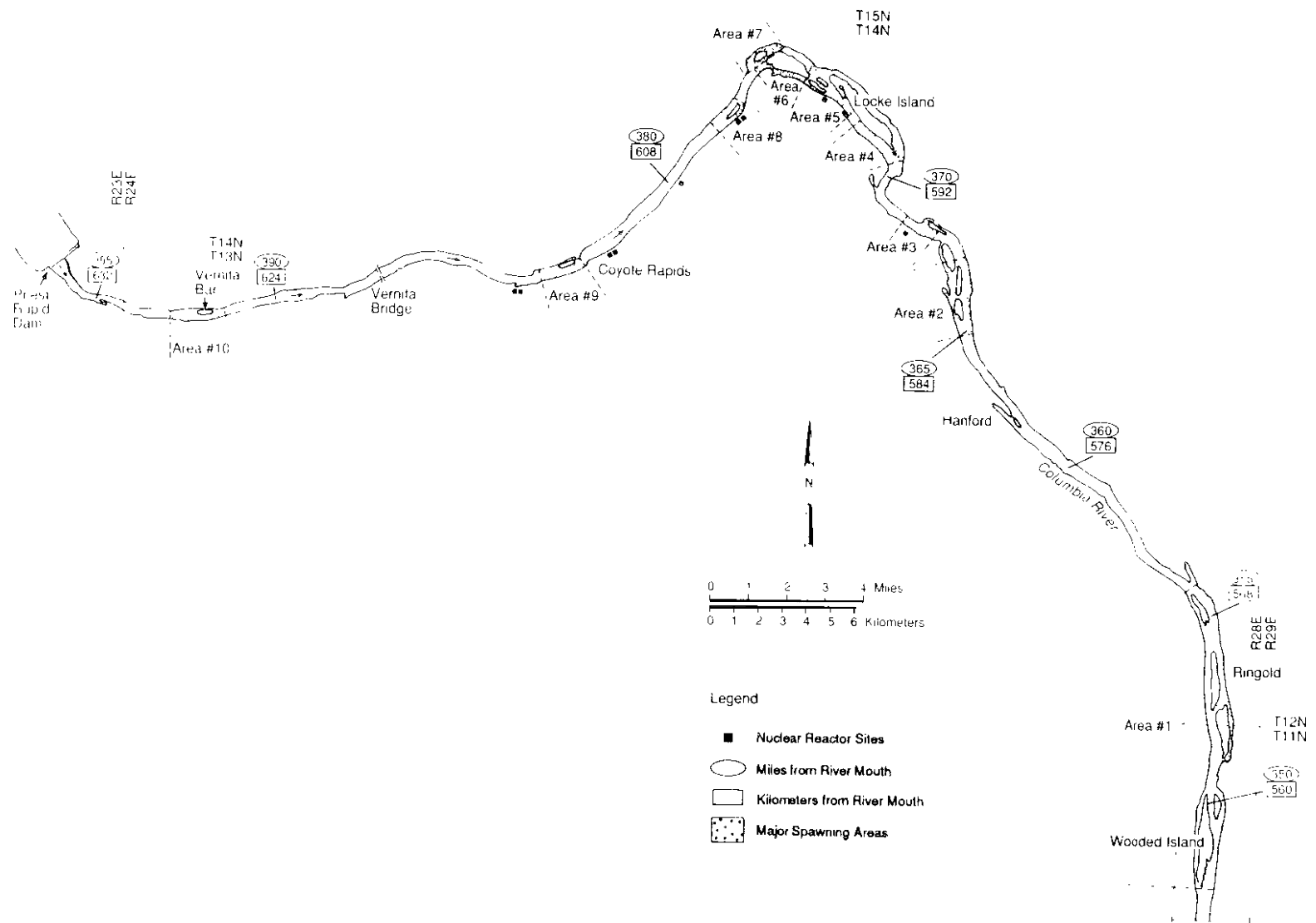


FIGURE 3.1. Major Fall Chinook Salmon Spawning Areas in the Hanford Reach of the Columbia River

Estimated numbers of visible redds ranged from a low of 65 in 1955 to a high of 8630 in 1987. Area 10 (Vemita Bar) and Area 5 (Upper Locke Island) were the most important spawning areas. Redd counts in these locations averaged 33 and 25% of the total, respectively, for the 41 years of record. Areas 2, 4, 6, and 7 collectively contained about 33% of the total redds from 1948 to 1988. Although the number of redds increased dramatically for Area 10 (Vemita Bar) after construction of Priest Rapids Dam (an average of 16% of the redds were counted there before 1960), changes in counts from other spawning areas generally reflected changes observed for the entire Hanford Reach. Minor spawning areas (average contribution <5% of the total number of redds observed) contributed up to 20% of the total redds observed for certain years. However, changes in their relative importance appeared related to a decrease in the number of fish spawning in the major spawning areas, rather than an increase in use of minor spawning areas. A summary of the Hanford spawning surveys by date and location is provided in Table A.1.

Trends in the number of redds observed at Hanford from 1948 to 1988 are shown in Figure 3.2. Redd counts ranged from <100 to about 1200 per year from 1948 to 1962. Counts increased to a peak of 4322 redds in 1969, then averaged about 2300 redds/year from 1971 to 1980. The number of redds increased steadily in the 1980s, and averaged over 8000 redds annually from 1985 to 1988.

Data from 1964 to 1988 was used to determine if there was a relationship between Hanford Reach redd counts and the escapement of adult fall chinook (Figure 3.3). This analysis indicates a strong correlation between the two variables. A plot of the residuals indicates that use of this regression equation to predict escapement may be limited at counts of <1000 redds. The redd-to-fish ratio also provides a population index. The redd-to-fish ratio based on adults plus jacks averaged 16.3:1 for 1964 to 1988 (range 5-39:1). A less variable ratio is achieved using dam passage counts of adults only (average 9.4:1, range 3.1-16:1). The wide range in redd-to-fish ratio shows the limited value of redd counts to obtain precise estimates of spawning populations.

3.3 TEMPERATURE AND FLOWS IN THE HANFORD REACH DURING SPAWNING

The range of temperatures over which fall chinook salmon spawn in the Hanford Reach each fall reflects the seasonal temperature cycle occurring in the Columbia River (Figure 3.4). Temperatures average about 16°C on October 1 and decline to about 9°C by the end of November. Fall chinook salmon spawned at temperatures (daily average) ranging from 12.0 to 18.5°C.

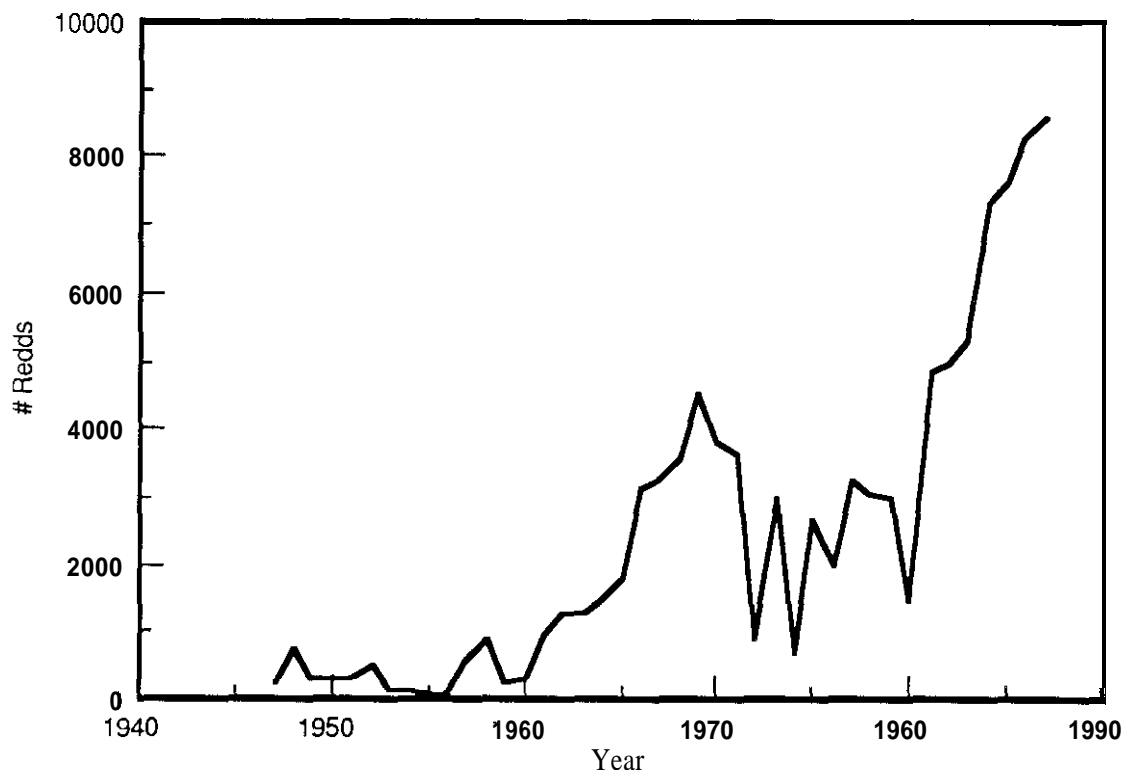


FIGURE 3.2. Long-Term Trend for Salmon Redds Observed During Aerial Surveys of the Hanford Reach

Weekly mean temperature at first observed spawning was 15.3°C for the 41 years from 1948 to 1988. About 75% of the spawning was initiated at weekly mean temperatures of 14 to 16°C (Figure 3.5). Daily average temperatures at peak spawning ranged from 6.8 to 15.5°C (median temperature 11.9°C). Weekly mean temperatures during peak spawning averaged 12.5°C for 1948 to 1988 (Figure 3.6). There was no significant difference ($t = 0.931$; $p = 0.36$) between weekly mean temperatures before and after construction of Priest Rapids Dam for the peak spawning period.

Daily average flows during redd surveys ranged from 1410 to $3790 \text{ m}^3/\text{s}$ ($50,000$ to $134,000 \text{ ft}^3/\text{s}$) from 1948 to 1988 ($N = 182$). Weekly average flows during peak spawning ranged from 1244 to $3276 \text{ m}^3/\text{s}$ ($44,000$ to $116,000 \text{ ft}^3/\text{s}$) and averaged $2203 \text{ m}^3/\text{s}$ ($78,000 \text{ ft}^3/\text{s}$) over this interval (Figure 3.7). The range of daily average discharge noted during peak spawning (Figure 3.8) ranged from about 1200 to $3800 \text{ m}^3/\text{s}$ from 1959 to 1985.

Weekly average flows during peak spawning were significantly higher (Mann-Whitney U Test: $Z = -1.758$; $p = 0.08$) after construction of Priest Rapids Dam. Weekly average flows during peak spawning averaged $2005 \text{ m}^3/\text{s}$ ($71,000 \text{ ft}^3/\text{s}$) from 1949 to 1959 (before the dam was

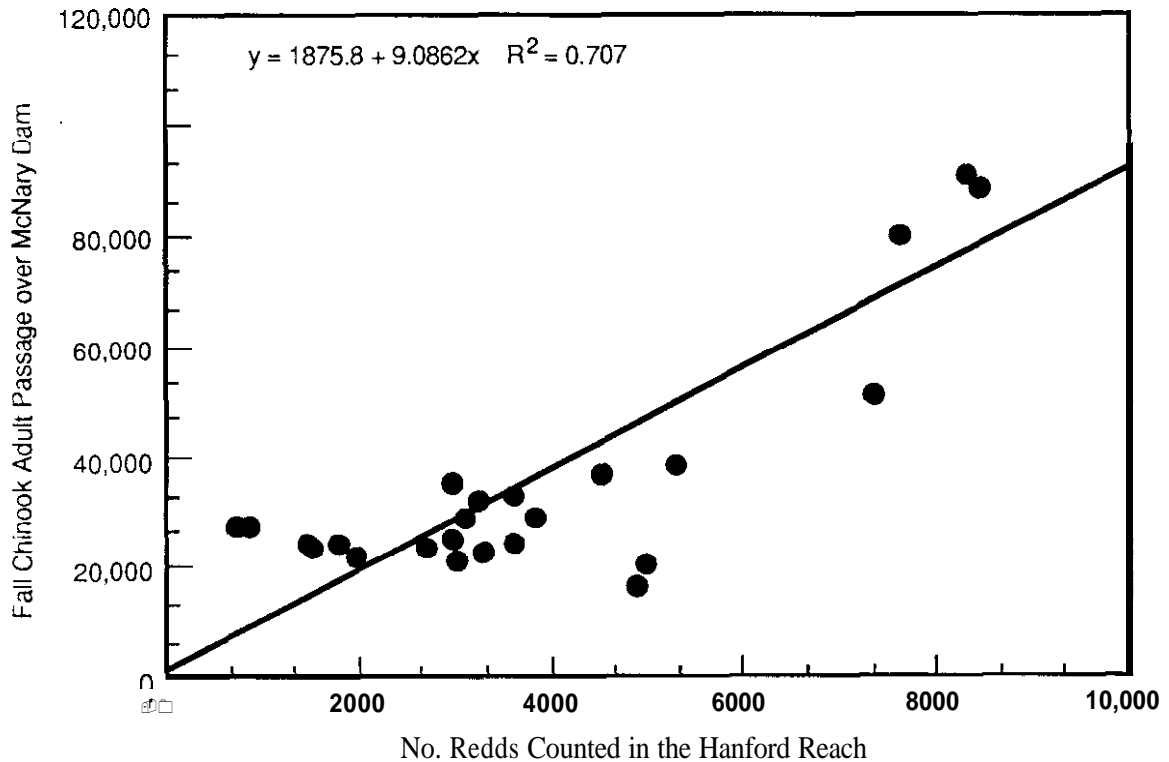


FIGURE 3.3. Relationship Between Adult Escapement over McNary Dam and Hanford Redd Counts

built) and 2287 m³/s (81,000 ft³/s) from 1960 to 1988. Increased flows are more likely due to changes in upstream storage practices rather than operation of Priest Rapids Dam because of its limited storage capacity relative to Grand Coulee Dam. The effects of increased flow during spawning are unknown. Bauersfeld (1978) and Chapman et al. (1983) speculated that higher flows may provide more spawning habitat by increasing the relative amount of shoreline area (i.e., bottom area). However, this would only be true within limits of available substrate size and velocity.

3.4 PHYSICAL HABITAT VARIABLES AFFECTING DISTRIBUTION OF REDDS

In addition to temperature and flow, substrate and river velocity affect the spatial distribution of redds. The depth at which fall chinook salmon spawn depends on daily and seasonal flows (discharge plus spill) at Priest Rapids Dam. Maximum spawning depth cannot be determined by aerial surveys because visibility is limited to depths < 2 to 4 m. Chapman et al. (1986) characterized the distribution of redds at Vemita Bar with SCUBA and reported that the range in spawning depth (i.e., depths between redds) varied as much as 8.5 m. Maximum depths where spawning was observed were 7 m at minimum regulated flows (1020 m³/s). Daily flow

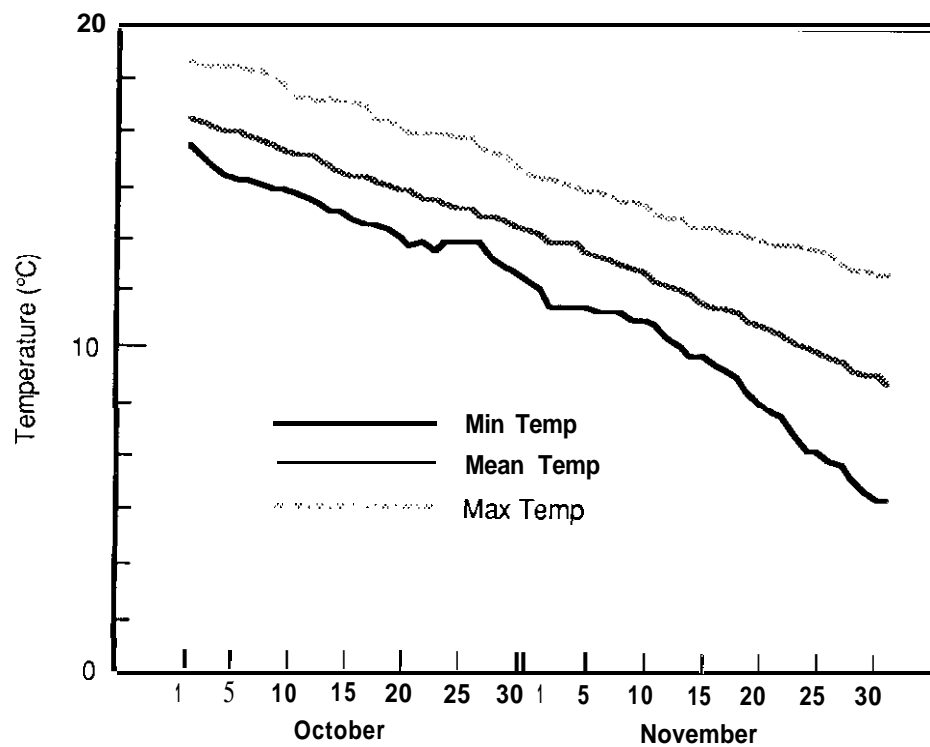


FIGURE 3.4 Daily Average Temperature. Range During Fall Chinook Salmon Spawning, 1965 to 1985

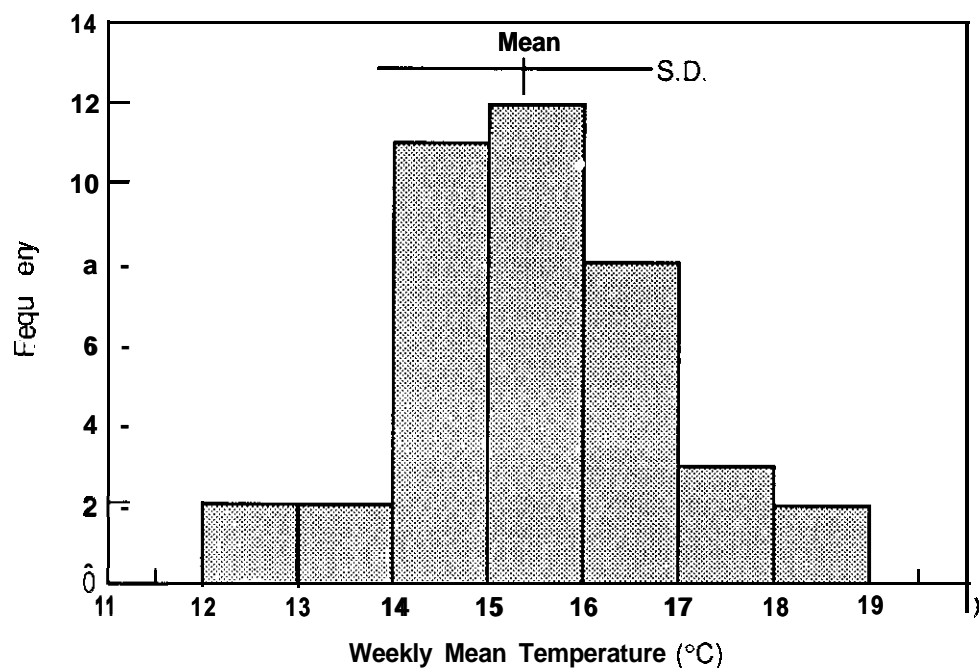


FIGURE 3.5 Frequency Plot of Weekly Mean Temperature at First Observed Spawning, 1949-1988

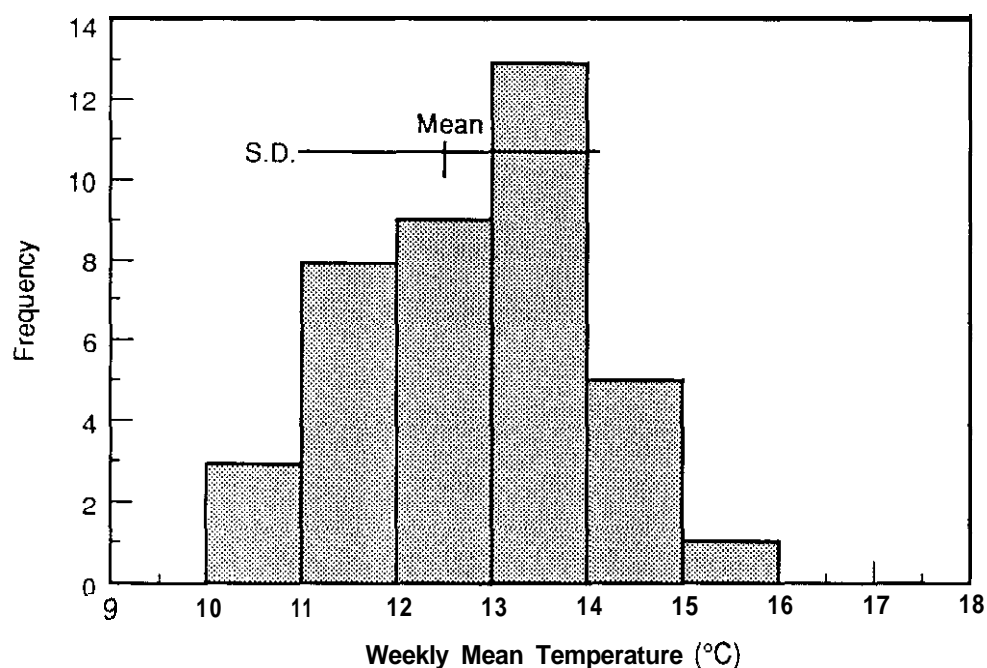


FIGURE 3.6. Frequency Plot of Weekly Mean Temperature at Peak Spawning, 1949-1988

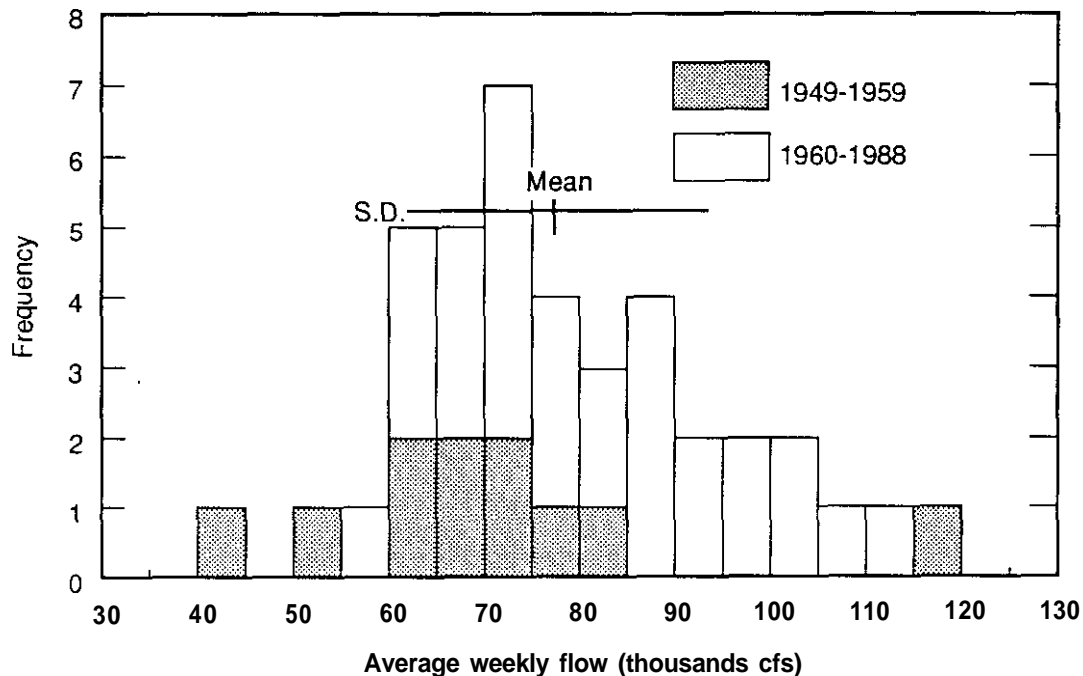


FIGURE 3.7. Frequency Plot of Average Weekly Flows During Peak Spawning. A comparison is made between flows before (1949-1959) and after (1960-1988) construction of Priest Rapids Dam.

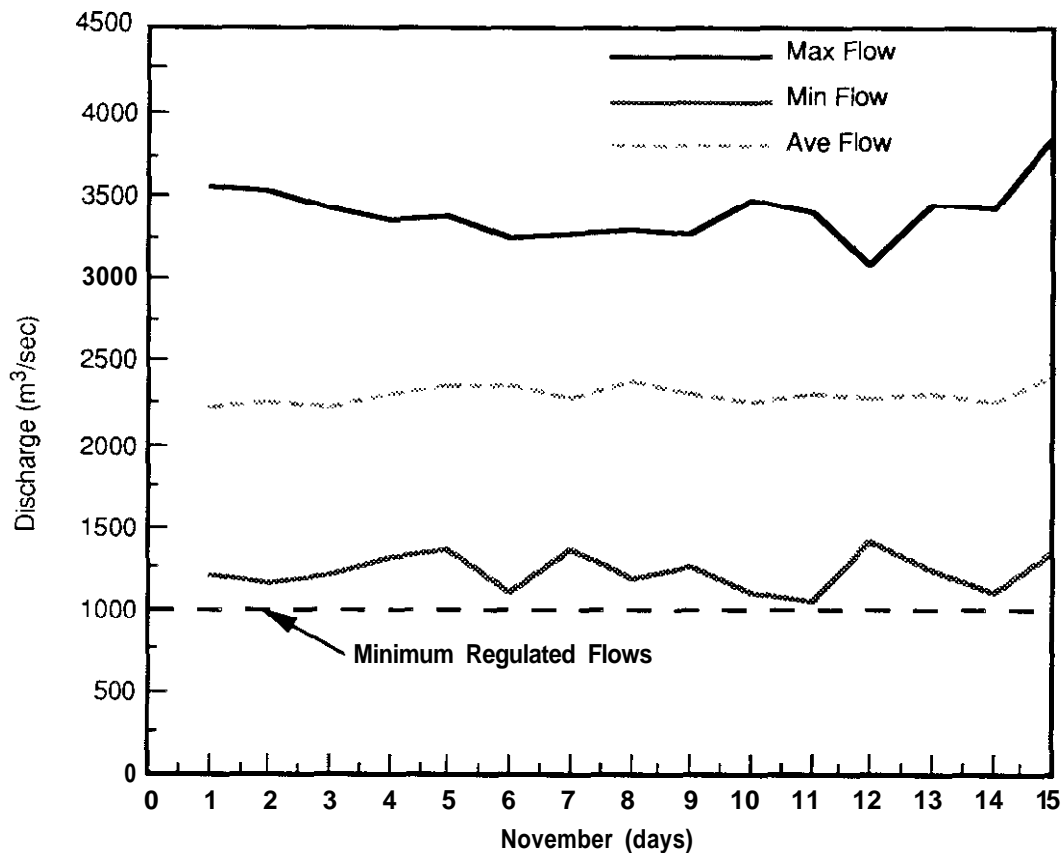


FIGURE 3.8. Range of Daily Average Discharge at Priest Rapids Dam During Peak Spawning, 1959-1985

patterns also influenced depths that salmon spawn. For example, fluctuations in discharge at Priest Rapids Dam caused water depths to fluctuate up to 4.5 m in areas where salmon spawned (Chapman et al. 1986).

To test the hypothesis that distribution of redds in the Hanford Reach was influenced by depth, the mean redd depth versus maximum channel depth (depths determined with the vegetation line representing the water surface) was plotted for five study areas in the upper Hanford Reach using data reported by Swan et al. (1988). Results indicated a nonsignificant regression between mean redd depth and channel depth ($F = 3.82$; $p = 0.15$). This suggests that, within these five locations, selection of spawning sites was not strongly influenced by available depth. Mean depth of redds in the study areas ranged from 1.0 to 7.5 m, where depth of channel ranged from 3 to 12 m. These depths are assumed high because the vegetation line is more indicative of annual average flows ($3500 \text{ m}^3/\text{s}$) than average flows that occur during spawning ($2200 \text{ m}^3/\text{s}$).

Presence of suitable substrate also affects the distribution of salmon redds. Substrate composition is usually characterized by visually estimating the composition of surface gravel (Platts et al. 1983). Other physical habitat variables that may influence selection of a spawning site (and survival of embryos and alevins) by adult salmon include percent fine sediments, dissolved oxygen, and intergravel permeability (reviewed in Chapman 1988).

Descriptions of five spawning areas reported by Swan et al. (1988) were used to evaluate the importance of substrate type (as percent composition based on particle size) to redd location. The most abundant substrate at all but one spawning area was rubble (10 to 20 cm diameter), and 61% of all redds occurred on this substrate. The hypothesis that overall distribution of redds was proportional to the distribution of substrate was also tested and rejected at $P < 0.001$. Although a significant difference was found between available substrate and spawning locations for three of the five study sites (chi square analysis, $p > 0.5$), the H_0 was rejected for spawning sites located at river km 594 and at river km 635. This suggests that redds were not equally distributed among available substrate types. Chapman et al. (1986) reported that 36% of the spawning substrate at Vernita Bar was cobble (rocks >76 mm diameter).

Salmon spawning at Hanford may also be influenced by flow velocities. A wide range in velocities over redd sites can be expected in the Hanford Reach because of fluctuating discharges at Priest Rapids Dam. Chapman et al. (1983) reported the near-bed velocities in spawning areas at Vernita Bar ranged from 0.20 to >1.95 m/s. A significant positive correlation ($r^2 > 0.82$) existed between depth and water velocity at each of three transects on Vernita Bar where data were collected (Chapman et al. 1983). Thus, these two variables cannot be treated independently. Although water velocity criteria for fall chinook salmon range from 0.186 to 0.805 m/s in Oregon (Smith 1973), chinook salmon spawn where velocities are as high as 1.14 m/s in the Columbia River (reviewed in Smith 1973).

3.5 MAJOR FACTORS INFLUENCING HANFORD REACH REDD COUNTS

Spawning surveys provided a relative measure of abundance for chinook salmon redds that can be observed from the air. The primary physical factors that influenced the ability to observe redds included depth of water over the redds and clarity of water. These factors are interrelated because water clarity also affects the maximum depth at which redds can be observed.

Wind action on the water surface reduced visibility, and strong winds influenced ability to control the position of the survey aircraft. Increased turbidity from eroded river banks and upstream construction activities also reduced visibility within localized areas. Available light also

limits the effectiveness of observing redds because redds in the deeper areas are not visible under heavy cloud cover. Meteorologic and hydrologic conditions often changed during a single survey flight. Thus, parts of the approximately 70 km spawning area could not be surveyed with the same degree of accuracy.

Spawning areas near Vemita Bar were more subject to flow changes from daytime release of water from Priest Rapids Dam than were downstream locations. The high rocky bluff on the south side of the river also casts shadows over part of the spawning area during the latter part of the season. The orientation of the river and direction of the river current also change in the Hanford Reach. These factors affect the influence of light and wind on visibility.

Changes in water depth and weather often occurred during a single flight. For example, salmon redds may be viewed at Vemita Bar under one scenario (say, 40,000 ft³/s) while redds viewed at Ringold (64 km downstream) may not experience similar flows until several hours later. Under the current operating regime at Priest Rapids Dam (i.e., decreased flows in the morning and increased flows at night since 1980), mid-day flows are always higher and depths greater at downstream locations than at Vemita Bar. Potential bias in redd counts because of inter-survey changes in water depth would be reduced only if minimum flow regimes were maintained at Priest Rapids Dam for >12 hr before aerial spawning surveys.

Beginning in 1979, redd surveys were conducted mainly on weekends because discharge at Priest Rapids Dam was usually regulated at lower levels. This schedule theoretically increased the likelihood of counting redds located in deeper water, which were not visible at higher flows. However, no significant difference (Mann-Whitney U Test: $z = -0.563$; $P = 0.57$) was found between flows at surveys taken on weekdays from 1949 to 1978 and flows at surveys taken on weekends from 1979 to 1988. Thus, changes in redd counts since 1979 are not related to changes in daily average flow during surveys.

In 1988, unpainted sheets of plywood (-1.2 M X 2.4 m) were sunk at four different depths near river km 595. The depth of these bottom markers was then correlated with shoreline markers placed on a concrete boat ramp that were visible from the air. The maximum depth for observing the plywood markers during three separate aerial surveys was 4 m. Similar measurements of salmon redds located in the main river channel were made during aerial surveys by observers in a BOAT. Measured depths for redds visible from the air ranged to 3 M. Collectively, these observations suggest that the upper depth limit for detecting redds during aerial surveys in 1988 was between 3 and 4 m. This compares with studies on Vemita Bar by Chapman et al. (1983) that reported redds in water depths >2.4 , (8 ft) could not be observed from aircraft.

For some parts of the Hanford Reach, accurate estimates of salmon redds were difficult to determine during peak spawning because redds were concentrated in high-use areas. For example, Swan et al. (1988) estimated a range of redd densities from 12 to 48 REDDS/acre for FIVE study sites in the Hanford Reach. Up to 186 REDDS/acre reported in areas of concentrated spawning. Extensive spawning on Vemita Bar (Area 10) and in Areas 2 through 7 results in superimposition and overlapping of redds. Chapman et al. (1983) reported that redd overlap occurred at the end of the spawning season because the early-spawning females could no longer defend their redds. Increased use of the Hanford Reach by returning adults may result in higher densities of redds if available spawning habitat is limited.

4.0 POPULATION CHARACTERISTICS

Management of AMADRP, PIS FOSJ populations is usually based on the annual escapement or numbers of FOSJ returning to the spawning grounds. Estimates of adult spawners, eggs deposited, and subsequent survival of embryos and juveniles to catchable size (for both commercial and sport fisheries) can then be factored to evaluate population status. This section summarizes population characteristics that influence adult spawning and outmigration of juveniles in the Hanford Reach.

3.1 ESCAPEMENT estimates

There are no estimates of fall chinook escapement to the Hanford Reach before completion of McNary (1953), Ice Harbor (1962), and Priest Rapids dams (1959). However, an estimate of URB escapement to the Hanford Reach can be obtained if the ratio of URB to lower Columbia River stocks is assumed to be similar for the period immediately after dam construction (3 to 7 years). For example, from relative proportions of fish passing McNary Dam from 1954 to 1956 (before construction of the Dalles Dam), those passing Priest Rapids Dam from 1960 to 1967, and those passing Ice Harbor Dam from 1962 to 1967 (before construction of John Day Dam), escapement estimates for the Hanford Reach range from 13,300 to 76,200 chinook salmon for 1948 to 1953. This compares with estimates of total escapement (jacks + adults) above Bonneville Dam ranging from 33,307 to 190,505 fish from 1948 to 1953 (Watson 1970).

The current status of the URB population in the Hanford Reach was estimated from the number of fall chinook salmon passing McNary, Priest Rapids, and Ice Harbor dams (based on USACE annual fish passage reports). Because counts after 1964 separate adults and jacks, the maximum number of adults reaching the spawning grounds for the last 25 years can be estimated. Data on sex ratios, fecundity, spawning success, and fry survival can then be used to estimate the numbers of juvenile outmigrants.

Returns of adult fall chinook salmon to the Hanford Reach ranged from about 16,000 to 38,000 fish from 1964 to 1983. Returns increased dramatically as has escapement over McNary Dam in recent years, and a peak estimate of 107,903 spawning adults was obtained in 1987 (Table 4.1). Estimated escapement to the spawning grounds from 1985 to 1988 was 16 to 22% lower than total returns because more fish were harvested by the sports fishery, and returns to the Priest Rapids Hatchery channel trap were increased. The increase in number of spawners reflects, in part, continued supplementation efforts at the Priest Rapids Hatchery. Current hydroelectric operations that allow increased flows during smolt outmigration may also increase survival of juvenile fall chinook from the Hanford Reach when they pass downriver dams.

TABLE 4.1. Estimated Run Size and Escapement of Fall Chinook Salmon to Spawning Grounds in the Hanford Reach, 1962-1988. Escapement equals passage of salmon over McNary Dam minus Ice Harbor and Priest Rapids dam passage totals, and are corrected to account for removal of fish by anglers and the Priest Rapids Hatchery. Estimates of escapement to the Yakima River, number of adults returning to the Priest Rapids Hatchery, and sport catch in the Hanford Reach are from Carlson and Dell (1989).

| Year | <u>Total Run Size</u> | <u>Total Adult Run</u> | <u>Spawning Escapement</u> |
|------|---------------------------|----------------------------|--------------------------------|
| 1962 | 3,985 | NA | NA |
| 1963 | 26,263 | NA | NA |
| 1964 | 32,736 | 24,322 | 24,032 |
| 1965 | 42,823 | 24,500 | 24,360 |
| 1966 | 41,360 | 28,551 | 28,079 |
| 1967 | 41,710 | 23,393 | 23,188 |
| 1968 | 37,349 | 24,318 | 24,067 |
| 1969 | 49,501 | 35,366 | 34,939 |
| 1970 | 34,797 | 27,616 | 26,748 |
| 1971 | 48,123 | 32,404 | 31,398 |
| 1972 | 34,089 | 27,501 | 26,749 |
| 1973 | 54,817 | 34,697 | 33,044 |
| 1974 | 51,577 | 26,910 | 25,847 |
| 1975 | 52,796 | 22,702 | 22,242 |
| 1976 | 75,743 | 21,733 | 21,140 |
| 1977 | 75,748 | 32,176 | 31,527 |
| 1978 | 36,013 | 21,349 | 20,578 |
| 1979 | 40,160 | 25,142 | 23,558 |
| 1980 | 28,725 | 21,047 | 20,266 |
| 1981 | 25,600 | 16,293 | 15,069 |
| 1982 | 40,670 | 20,640 | 20,540 |
| 1983 | 60,398 | 38,209 | 36,983 |
| 1984 | 95,439 | 49,103 | 44,874 |
| 1985 | 173,894 | 74,464 | 43,607 |
| 1986 | 205,263 | 87,042 | 75,928 |
| 1987 | 152,611 | 107,903 | 90,553 |
| 1988 | 136,154 | 83,315 | 73,717 |

Jack:adult ratios differ between Bonneville Dam (includes both tule and URB counts) and McNary Dam (URB only). Although the relative proportion varies among years, the trends are usually consistent for all Columbia River dams, particularly during the last 10 to 15 years (Table 4.2). In general, a greater proportion of jacks occur in the total escapement to the Hanford Reach than at Bonneville Dam. Since 1960, jack:adult ratios for passage over Priest Rapids and Ice Harbor dams were more variable than jack:adult ratios for the Hanford Reach and McNary Dam.

The relative use of the Hanford Reach has increased from about 60% of the total URB run above McNary Dam in the 1960s to nearly 80% of the run in recent years (Figure 4.1). The proportion of adult fall chinook passing Priest Rapids Dam to upstream spawning areas has remained stable during this interval. For example, an average of about 18% of the McNary Dam count was destined for spawning areas upstream of Priest Rapids Dam from 1970 to 1988. However, the total run size past Priest Rapids Dam has increased dramatically because of the increase in overall run size. Numbers of fall chinook salmon over Priest Rapids Dam increased from about 5,000 fish per year in 1978-1981 to about 21,000 fish per year from 1985 to 1988. In contrast, the proportion of the run entering the Snake River (based on passage counts over Ice Harbor Dam) has declined in the last 20 years from 40% to less than 5% of the total number of fish passing McNary Dam. The decline in chinook salmon runs to the Snake River has been attributed to losses of juvenile salmon during turbine passage and to migration delay caused by reservoirs (Raymond 1979). Also, Ice Harbor, Oxbow, and Brownlee dams flooded or blocked access to former spawning areas used by fall chinook salmon in the Snake River drainage (Fulton 1968).

4.2 POPULATION STRUCTURE

Salmon returning to spawn in the Hanford Reach currently originate from wild, or naturally spawning (Hanford Reach), and hatchery populations (Ringold and Priest Rapids hatcheries). The age structure and sex ratios of these populations were determined by the Washington Department of Fisheries in 1987 (Roler 1988; Figure 4.2). All 2-year-old salmon and most 3-year-old fish were males. However, the male:female ratio was about 35:65 for fish returning to the Hanford Reach and Priest Rapids Hatchery at ages 4 and 5. Sex ratios for Priest Rapids Hatchery and Hanford Reach populations were similar (Figure 4.2). However, a greater proportion of males returned to the Ringold Hatchery, mainly because of the high number of jacks at ages 1 and 2.

Age data were examined from two different groups where information was available (adult returns from 1966 to 1979 and 1983 to 1987) to determine if the age structure of fall chinook in the Hanford Reach had changed after hatchery releases were increased. A chi-square analysis

TABLE 4.2. Contribution of Jacks to Total Run of Columbia River Fall Chinook Salmon, 1960-1988. Values are given as a percent of the total run passing each river dam.

| Year | Location in Columbia River | | | | | | |
|------|----------------------------|---------------|-------------|-----------|------------------|---------------|---------------|
| | Bonneville(a) | The Dalles(a) | John Day(a) | McNary(a) | Priest Rapids(b) | Ice Harbor(B) | Hanford Reach |
| 1960 | 11 | | | 23 | 24 | | |
| 1961 | 13 | | | 28 | 41 | | |
| 1962 | 8 | 14 | | 18 | 22 | | |
| 1963 | 23 | 49 | | 53 | 80 | | |
| 1964 | 10 | 28 | | 31 | 53 | 18 | 26 |
| 1965 | 28 | 50 | | 46 | 61 | 34 | 42 |
| 1966 | 18 | 21 | | 32 | 50 | 15 | 30 |
| 1967 | 28 | 55 | | 41 | 58 | 26 | 43 |
| 1968 | 23 | 34 | 42 | 32 | 52 | 20 | 34 |
| 1969 | 30 | 50 | 5.5 | 30 | 61 | 22 | 22 |
| 1970 | 24 | 49 | 50 | 30 | 68 | 13 | 15 |
| 1971 | 24 | 49 | 48 | 30 | 33 | 15 | 32 |
| 1972 | 31 | 56 | 64 | 24 | 60 | 20 | 17 |
| 1973 | 30 | 45 | 52 | 36 | 52 | 19 | 36 |
| 1974 | 33 | 55 | 56 | 44 | 34 | 15 | 48 |
| 1975 | 21 | 48 | 58 | 57 | 6X | 25 | 57 |
| 1976 | 30 | 55 | 65 | 67 | 49 | 25 | 71 |
| 1977 | 36 | 46 | 59 | 55 | 41 | 31 | 57 |
| 197x | 28 | 35 | 46 | 36 | 27 | 31 | 40 |
| 1979 | 24 | 39 | 49 | 37 | 37 | 41 | 38 |
| 1980 | 17 | 20 | 31 | 23 | 29 | 33 | 21 |
| 1981 | 31 | 40 | 50 | 37 | 30 | 63 | 34 |
| 1982 | 28 | 49 | 55 | 46 | 33 | 54 | 49 |
| 19x3 | 31 | 36 | 43 | 34 | 22 | 35 | 37 |
| 1984 | 40(c) | 43(c) | 47(c) | 45(c) | 38 | 33(c) | 48 |
| 1985 | 45(c) | 50(c) | 57(c) | 54(c) | 45 | 78(c) | 54 |
| 1986 | 46(c) | 51(c) | 51(c) | 53(c) | 36 | 46(c) | 57 |
| 1987 | 17(c) | 19(c) | 20(c) | 23(c) | 12 | 19(c) | 29 |
| 1988 | 20(d) | | | 32(d) | 17(d) | 35(d) | 37 |

(a) From H. Jensen, Oregon Department of Fish & Wildlife (ODFW), personal communication.

(b) From M. B. Dell, Grant Co. Public Utility District (PUD), personal communication.

(c) From U.S. Army Corps of Engineers Annual Fish Passage Reports.

(d) From U.S. Army Corps of Engineers 1988 Daily Summary Fish Report.

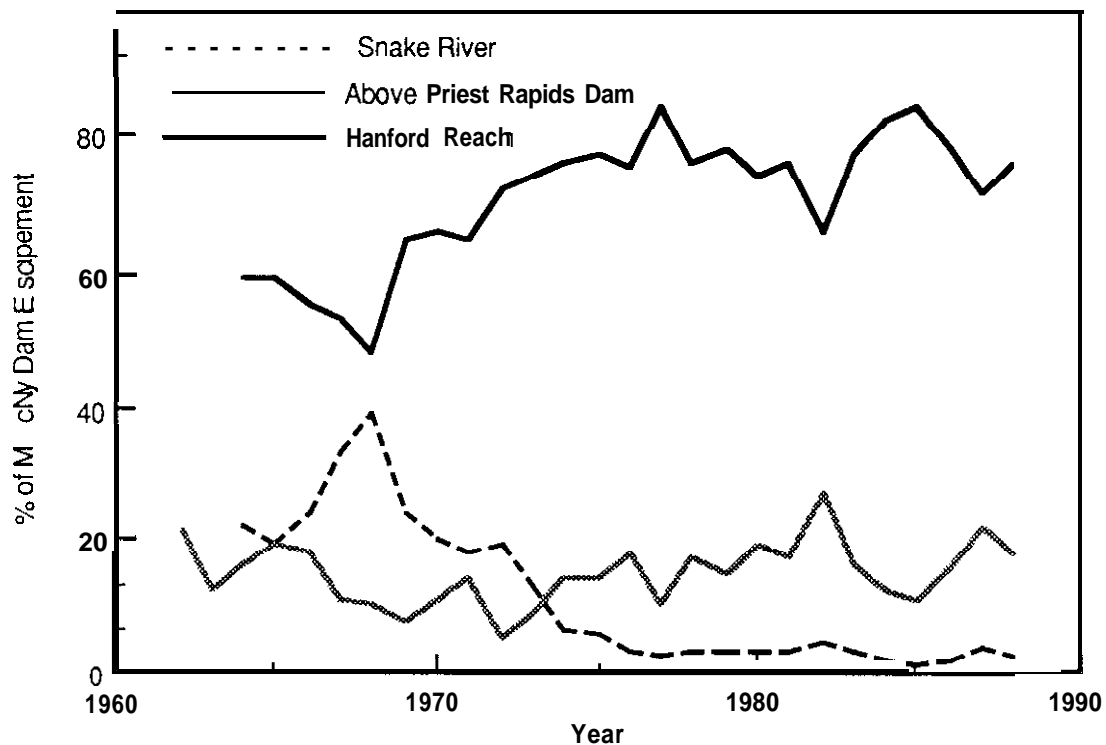


FIGURE 4.1. Destination of Adult Fall Chinook Salmon Passing McNary Dam, 1962-1988

indicated that the age distribution of these two groups was significantly different at $p < 0.001$. It appeared that a greater proportion of age 2 salmon were present in 1983-1987 populations than in the 1966-1979 grouping (Figure 4.3).

4.3 CONTRIBUTION OF HANFORD REACH SALMON TO THE FISHERY

The relative contribution of Hanford stocks (URB) to fall chinook salmon runs in the Columbia River increased from about 24% of the total in the early 1980s to 50 to 60% of the total in recent years (Table 4.3). This change is mainly a result of the increased numbers of IJRB adults returning to the Hanford Reach, rather than a decline in other fall chinook salmon stocks. Although LRH stocks have also shown a marked increase in population size, numbers of Bonneville Pool Hatchery (BPH) fish have declined significantly during the same interval. The lower Columbia River wild (LRW) stocks historically have been the least abundant of the fall chinook stocks, and run size has fluctuated from about 4 to 13% of the total run to the Columbia River.

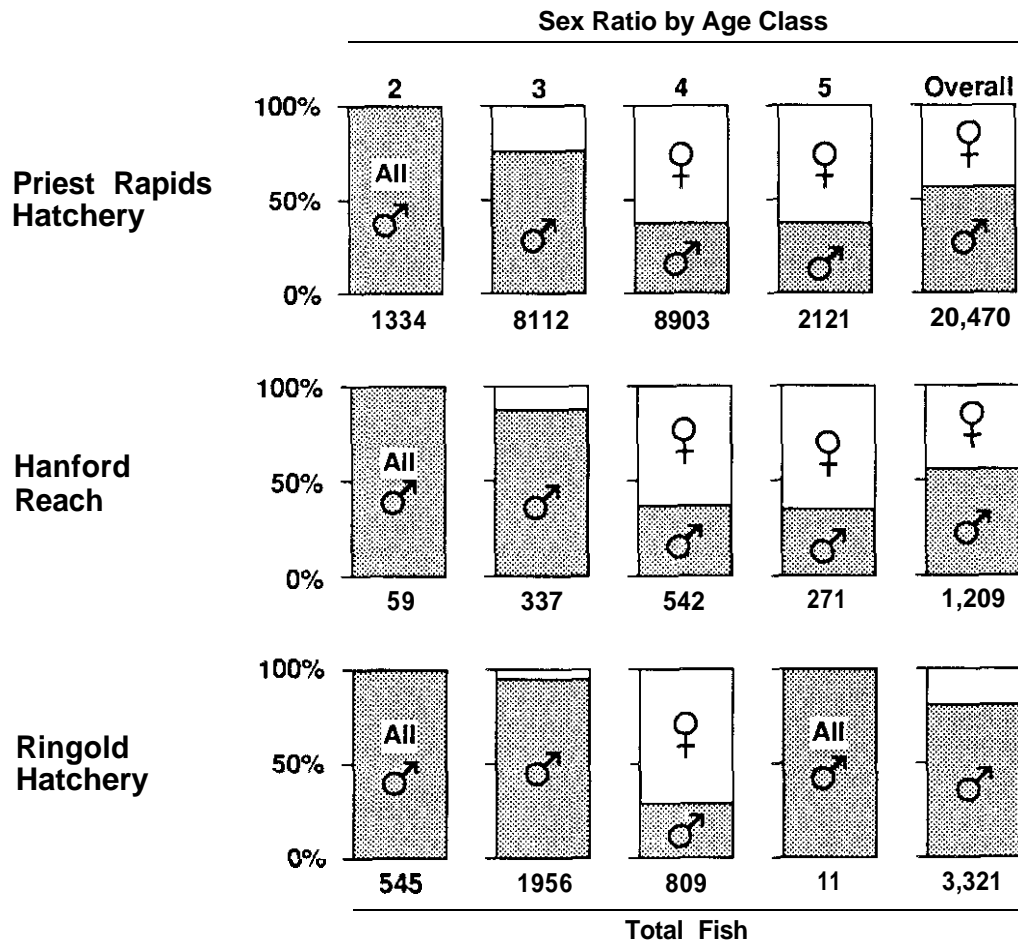


FIGURE 4.2. Sex Ratios for Different Age Classes of Hatchery and Naturally Spawning Upriver Bright Fall Chinook Salmon (data from Roler 1988)

The relative importance of URB salmon to the commercial and sport fisheries in the Columbia River is summarized in Table 4.4. No distinct trends were obvious for total catch of fall chinook salmon from 1980 to 1985. However, fall chinook populations increased nearly three-fold from 1985 to 1988. The relative contribution of URB to the commercial, tribal, and sport fisheries has increased since 1980. In 1988, URB comprised 28, 96, and 39% of the commercial, /tribal, and sport fish catch of fall chinook salmon in the Columbia River, respectively (Table 4.4). Increased contribution of URB fall chinook salmon to the total harvest of fall chinook may be explained in part, by court decisions that have shifted much of the harvest from in-river commercial (zone 1-5) to tribal (zone 6) (Homer and Bjornn 1979).

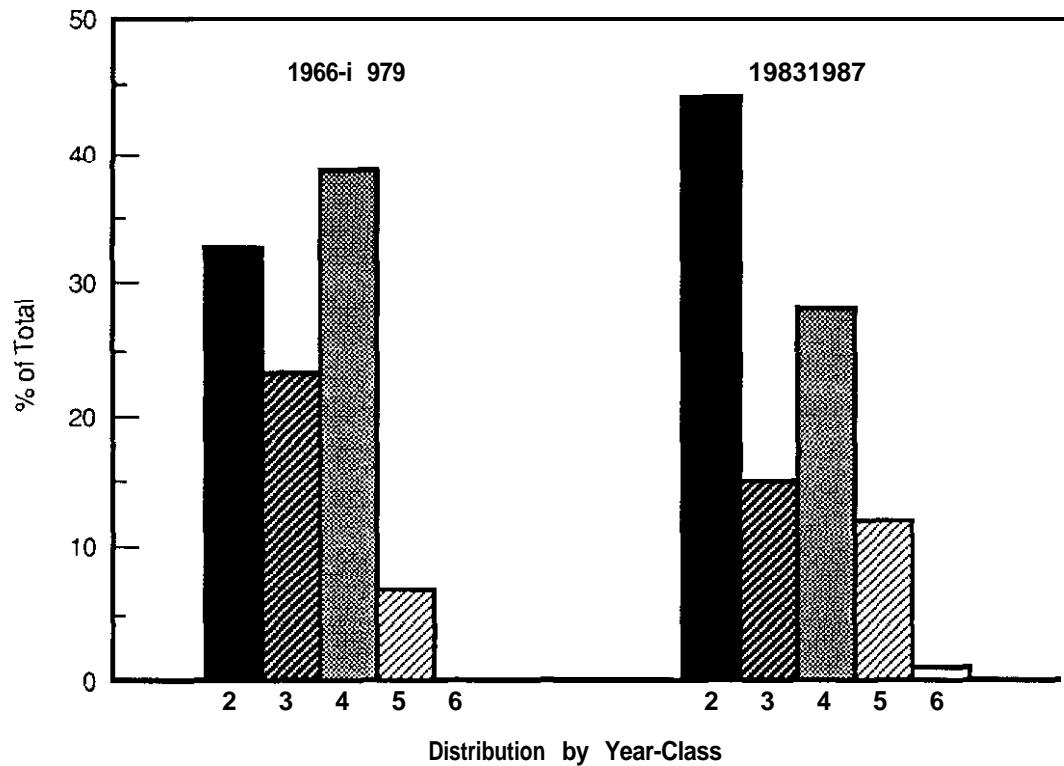


FIGURE 4.3. Age Composition of Upriver Bright Fall Chinook Salmon Populations (modified from Roler 1988)

TABLE 4.3. Relative Contribution (in thousands of fish) of Upriver Bright and Other Fall Chinook Salmon Stocks to Total Runs of Columbia River Fall Chinook Salmon, 1980-1988 (ODFW/WDF 1989)

| Year | URB | BPH | LRH | LRW | Total |
|------|-------|-------|-------|------|-------|
| 1980 | 76.8 | 97.8 | 105.6 | 38.8 | 319.0 |
| 1981 | 66.6 | 86.3 | 94.9 | 25.0 | 272.8 |
| 1982 | 79.0 | 120.7 | 139.5 | 13.0 | 342.2 |
| 1983 | 86.1 | 28.9 | 88.1 | 16.5 | 219.9 |
| 1984 | 131.4 | 47.5 | 102.4 | 13.3 | 294.6 |
| 1985 | 195.6 | 33.0 | 111.0 | 13.3 | 352.9 |
| 1986 | 281.5 | 16.5 | 154.9 | 24.8 | 477.7 |
| 1987 | 419.4 | 9.1 | 344.2 | 37.9 | 810.6 |
| 1988 | 339.9 | 12.3 | 309.9 | 41.7 | 703.8 |

URB = Upriver bright.
BPH = Bonneville Pool Hatchery.

LRH = Lower River Hatchery
LRW = Lower River wild.

TABLE 4.4. Catch Statistics for Upriver Bright Fall Chinook Salmon and Relative Importance of the URB Catch (based on total fall chinook salmon harvest) to Commercial and Sport Fisheries in the Columbia River, 1981-1988. Total catch values are based on recoveries of coded wire tags (ODFW/WDF 1989).

| Year | Total Catch (thousands) | | | | URB as % of Fall Chinook Catch | | | |
|------|-------------------------|------------------|--------------------|----------------|--------------------------------|---------------------|----------------|----------------|
| | Commercial Zone | Tribal 1-5(a) | Sport Zone 6(b) | Total Catch | Commercial Zone 1-5(a) | Tribal Zone 6(b) | Sport Catch | Total Catch |
| 1980 | 112.3 | 32.6 | 5.2 | 150.1 | 4.5 | 27.6 | 5.2 | 10.0 |
| 19x1 | 28.7 | 47.5 | 4.7 | 80.9 | 18.4 | 28.2 | 14.9 | 20.4 |
| 1982 | X8.7 | 52.7 | 5.4 | 146.8 | 5.1 | 5.3 | 3.7 | 5.1 |
| 19x3 | 23.4 | 20.9 | 3.8 | 48.1 | 18.4 | 58.4 | 18.4 | 35.7 |
| 1984 | 59.2 | 49.6 | 17.2 | 126.0 | 40.0 | 58.5 | 25.6 | 45.6 |
| 1985 | 55.8 | 67.1 | 15.9 | 138.8 | 61.8 | 80.9 | 57.2 | 70.5 |
| 1986 | 147.1 | 96.2 | 24.1 | 267.4 | 39.1 | 93.3 | 44.8 | 58.7 |
| 1987 | 302.1 | 122.5 | 55.9 | 480.5 | 34.5 | 98.0 | 32.6 | 50.5 |
| 1988 | 280.8 | 124.0 | 42.2 | 447.0 | 28.4 | 96.1 | 39.1 | 48.2 |

(a) Zone 1-5 includes Columbia River mouth to river km 235.

(b) Zone 6 includes river km 253-470.

5.0 FACTORS AFFECTING ABUNDANCE OF FALL CHINOOK SALMON IN THE HANFORD REACH

The size of the fall chinook salmon population in the Hanford Reach is influenced by several variables, including adult spawning habitat, egg-to-fry survival of the naturally spawning population, numbers of juvenile hatchery fish released into the Hanford Reach, survival of smolts during downstream migration, ocean survival, and harvest by ocean and in-river fisheries (Figure 5.1) Each variable is discussed in some detail below.

5.1 AVAILABLE SPAWNING HABITAT

Our aerial surveys indicate little recruitment of spawners to new areas that appear to be suitable for spawning. Rather, spawning densities appear to be increasing in high-use areas. Other areas of the Hanford Reach remain relatively unused. The extent of spawning in deep water areas where visibility from aircraft is restricted is largely unknown. However, Swan (1989) speculated that up to 80% of fall chinook salmon in the Hanford Reach may spawn in water too deep to detect by aircraft. This estimate was based on the difference between dam passage counts of adult salmon and aerial estimates of redds. But, it likely overestimates the relative importance of deep water areas to salmon spawning because it assumes 100% of the redds in shallow-water areas are counted during aerial surveys.

Our aerial surveys indicate that extensive overlapping of redds occurs in the heavily used spawning areas. Swan (1989) also found that deep-water (>3 m depth) redds commonly overlapped during the latter part of the spawning season. The impact of this on fry production is unknown. But, superimposition of redds in high use areas could disrupt egg pockets and reduce production in areas where suitable spawning habitat is limited. Chapman et al. (1983) did not note extensive superimposition of redds at Vemita Bar from 1978 to 1980. However, escapement of fall chinook salmon to the Hanford Reach has increased almost four-fold since then.

It is clear that fall chinook salmon spawn over a wide range of conditions in the Hanford Reach. Thus, further studies on habitat requirements and physical factors influencing spawning site selection are needed to acquire a better understanding of the current use of spawning sites and resultant carrying capacity of the Hanford Reach for fall chinook salmon.

5.2 EGG-TO-SMOLT SURVIVAL

Increased variability in flow during incubation and hatching has created a major change in environmental conditions for fall chinook salmon populations over the last 40 years. These

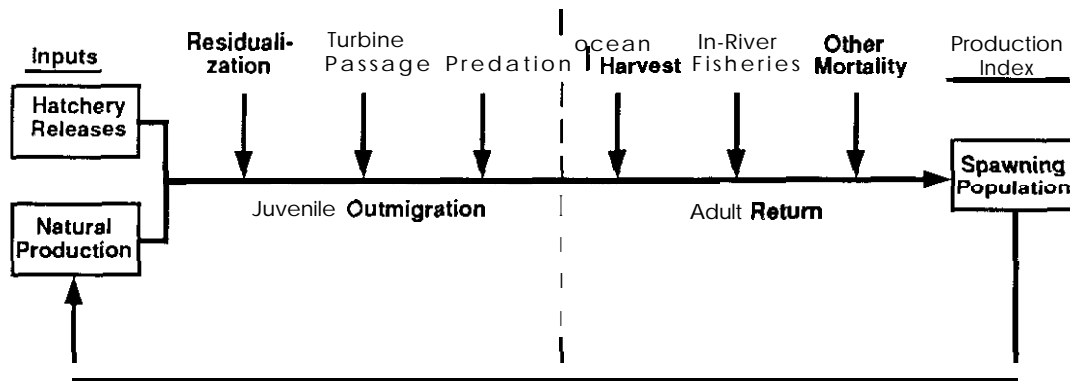


FIGURE 5.1. Conceptual Diagram Illustrating Major Variables Affecting Production of Fall Chinook Salmon During Their Life Cycle

changes in flow may affect the survival of developing eggs and embryos (desiccation), and emergent fry (stranding). Variable flows are due to construction of upstream dams that store and release water in response to irrigation and power demands. Water storage practices have altered both seasonal and daily flow patterns. Seasonal flows in the Hanford Reach have been more variable since the construction of Grand Coulee Dam in 1941. Increased variation in weekly and daily flows was evident beginning in the mid-1950s (Figure 5.2). Average discharge during the spawning period also appears to have increased in the last 40 years. Diel flow variation during spawning is extensive (Figure 5.3). Mean ratios of maximum to minimum daily discharge at Priest Rapids Dam ranged from 2.2 to 4.3 from 1972 to 1986 (Table 5.1).

Short-term fluctuations in flow that expose redds above the water surface may not impact the survival of salmonid life-stages developing in the gravel if adequate ground water (bank storage) is available to maintain intergravel flows (Meekin 1967; Neitzel et al. 1984). However, the range of flows necessary for survival can change during the over-winter incubation period. For example, pre-hatch stages of salmonids are more tolerant of dewatering than post-hatch stages (Becker and Neitzel 1985). Cleavage eggs and embryos can obtain oxygen from air by diffusion if moisture and temperature conditions are favorable. In contrast, eleutheroembryos and alevins require oxygenated water for respiration (Becker and Neitzel 1985). Extended periods of low flow occurring after fry emergence have caused mortality of juvenile fall chinook salmon in the Hanford Reach because of desiccation and stranding (Page 1976; Bauersfeld 1978).

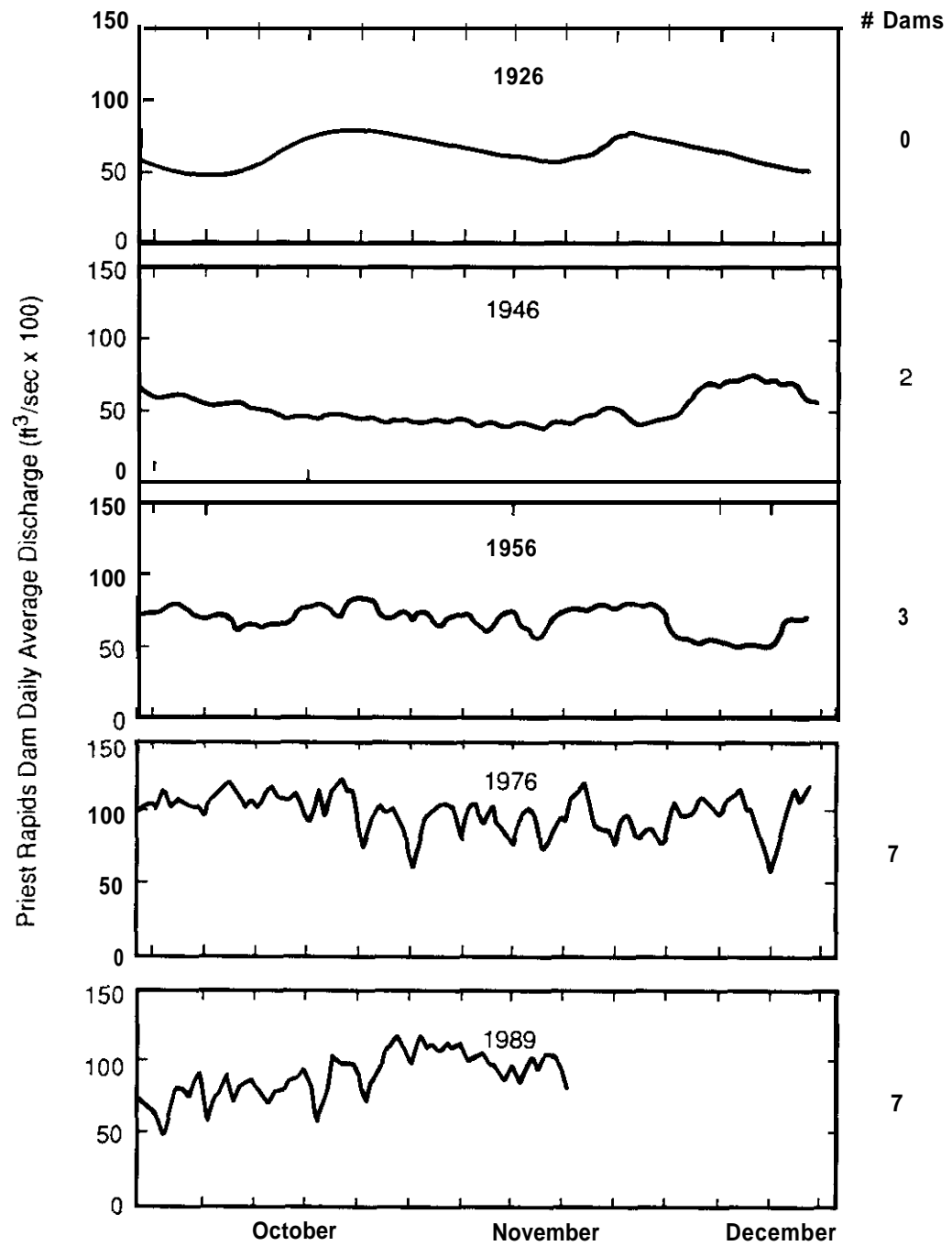


FIGURE 5.2. Historical Changes in Seasonal Flow Patterns in the Hanford Reach During Fall Chinook Salmon Spawning

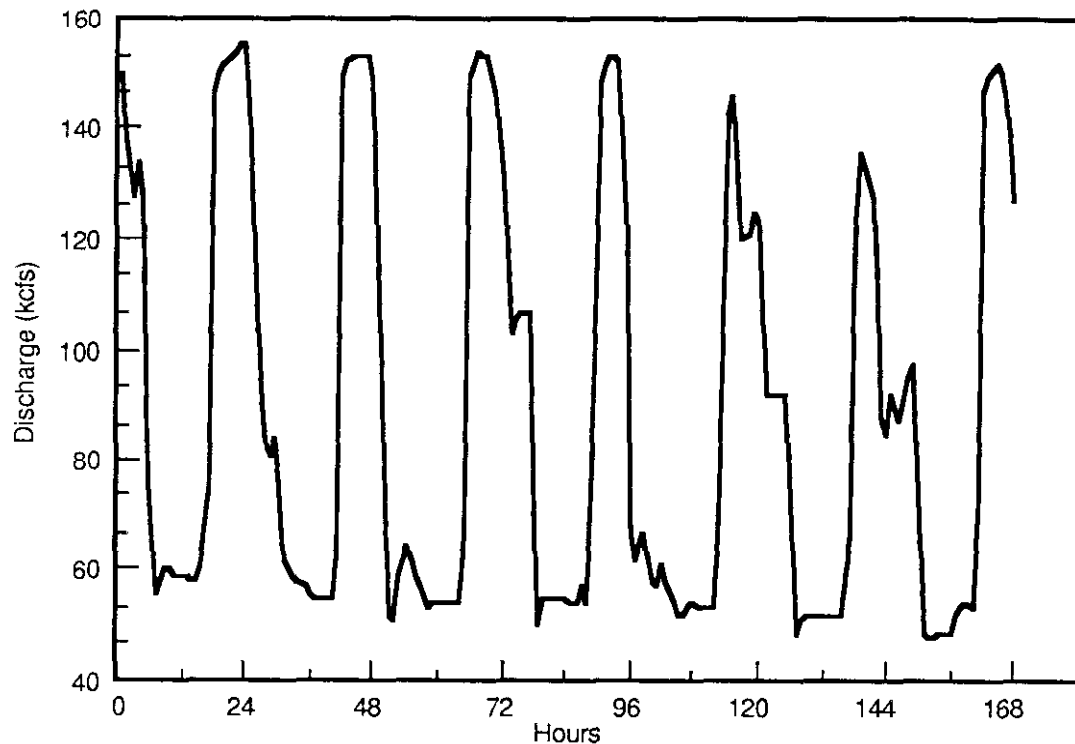


FIGURE 5.3. Range of Flows During the Peak Spawning Period in November 1988

5.3 HATCHERY CONTRIBUTION

Juvenile hatchery fall chinook salmon released to the Hanford Reach have supplemented wild run production since the early 1960s and numbers have increased dramatically in recent years (Table 5.2). Initial releases of fish were from the Ringold rearing ponds and/or from the Priest Rapids Dam (PRD) spawning channel. Adult returns from these facilities first occurred in 1965 and 1967, respectively (Allen 1977). Maximum production from the PRD spawning channel occurred in 1968 when approximately 7 million fish were released. This facility was built in 1963 to mitigate the loss of chinook salmon spawning grounds resulting from construction of Priest Rapids and Wanapum dams (Allen and Meekin 1973). The spawning channel had several problems, including adult pre-spawning mortalities, siltation of developing embryos, and poor adult returns. The last release of juvenile fish from the spawning channel occurred in 1978.

Upriver bright fall chinook salmon were trapped in the fish ladders at Priest Rapids Dam for use in artificial propagation efforts at the PRD spawning channel and the hatchery (Horner and Bjornn 1979; Becker 1985). An average of 35% (range 10 to 66%) of the adult upriver run was

TABLE 5.1. Diel Flow Variation in the Hanford Reach During Fall Chinook Salmon Spawning, 1972-1986. Values represent the mean ratio of maximum to minimum daily discharge at Priest Rapids Dam.

| Year | <u>October</u> | <u>November</u> |
|------|----------------|-----------------|
| 1972 | 2.6 | 2.5 |
| 1973 | 2.9 | 2.2 |
| 1974 | 2.6 | 2.9 |
| 1975 | 2.3 | 2.2 |
| 1976 | 2.4 | 2.4 |
| 1977 | 2.7 | 3.5 |
| 1978 | 2.7 | 3.7 |
| 1979 | 3.2 | 4.3 |
| 1980 | 3.3 | 4.3 |
| 1981 | 2.7 | 4.0 |
| 1982 | 3.1 | 4.1 |
| 1983 | 2.3 | 2.2 |
| 1984 | 2.6 | 2.5 |
| 1985 | 2.5 | 2.8 |
| 1986 | 3.0 | 2.8 |

removed for this purpose from 1963 to 1982 (M.B. Dell, Grant County PUD, personal communication). This practice reduced the number of fish available to seed upstream spawning areas below Wanapum and Rocky Reach dams (Mathews and Paulik 1967) and may have eliminated spawning off the mouth of the Wenatchee River (Mullan 1987). In recent years, adult returns to the Priest Rapids Hatchery outlet stream have satisfied most of the hatchery egg requirements, and ladder trapping has been reduced or eliminated. Thus, spawning by fall chinook salmon above the Hanford Reach may be expected to increase.

Releases of juvenile fall chinook salmon from the Ringold rearing facility were irregular, but averaged about 1 million smolts/year for 19 of the last 27 years when fish were released. Egg sources for Ringold releases have included the Klickitat, Spring Creek, Abernathy, Bonneville, and Priest Rapids hatcheries. Fish were released as fry, fingerlings, or yearlings.

The PRD hatchery has been used to supplement the naturally spawning fall chinook salmon runs since 1973. Of the approximately 8.5 million hatchery fish released annually to the Hanford Reach from 1981 to 1988, >80% originated from the PRD hatchery. Adult fall chinook salmon

TABLE 5.2. Releases of Juvenile Fall Chinook Salmon from the Priest Rapids Dam (PRD) and Ringold Rearing Facilities, 1962-1988 (From M.B. Dell, Grant County Public Utility District, personal communication)

| <u>Release Year</u> | <u>Number Released (millions)</u> | | | | <u>Total</u> |
|-------------------------|-------------------------------------|-------------------------|----------------|---------------------|--------------|
| | <u>PRD Spawning Channel</u> | <u>PRD Hatchery</u> | <u>Ringold</u> | <u>Other</u> | |
| 1962 | 0 | 0 | 0.02 | 0 | 0.02 |
| 1963 | 0 | 0 | 0.04 | 0 | 0.04 |
| 1964 | 1.07 | 0 | 0.19 | 0 | 1.26 |
| 1965 | 0.35 | 0 | 0.01 | 0 | 0.36 |
| 1966 | 1.18 | 0 | 0.17 | 0 | 1.35 |
| 1967 | 1.47 | 0 | 0.51 | 0 | 1.98 |
| 1968 | 7.14 | 0 | 1.84 | 0 | 8.98 |
| 1969 | 2.99 | 0 | 2.50 | 0 | 5.49 |
| 1970 | 2.00 | 0 | 0 | 0 | 2.00 |
| 1971 | 1.80 | 0 | 2.31 | 0 | 4.11 |
| 1972 | 2.85 | 0 | 1.32 | 0 | 4.17 |
| 1973 | 0.41 | 0.26 | 0 | 0 | 0.66 |
| 1974 | 0.54 | 2.37 | 1.75 | 0 | 4.66 |
| 1975 | 0.72 | 0.56 | 0 | 0 | 1.29 |
| 1976 | 0.55 | 1.34 | 0.90 | 0 | 2.79 |
| 1977 | 0.31 | 0.91 | 0 | 0 | 1.22 |
| 1978 | 0.04 | 1.42 | 0.50 | 0 | 1.96 |
| 1979 | 0 | 1.20 | 0 | 0 | 1.20 |
| 1980 | 0 | 2.71 | 0.94 | 0 | 3.65 |
| 1981 | 0 | 4.83 | 0 | 0 | 4.83 |
| 1982 | 0 | 5.51 | 0.79 | 0 | 6.30 |
| 1983 | 0 | 10.30 | 0 | 1.32 | 11.62 |
| 1984 | 0 | 9.74 | 2.10 | 0 | 11.84 |
| 1985 | 0 | 6.99 | 1.20 | 0.14 | 9.33 |
| 1986 | 0 | 6.36 | 1.30 | 0.20 | 7.86 |
| 1987 | 0 | 6.05 | 1.10 | 1.04 ^(a) | 8.19 |
| 1988 | 0 | 7.71 | 0 | 0 | 7.71 |

(a) Transferred to the Yakima River for release.

that return to the hatchery outlet stream, or are trapped in the fish ladders at Priest Rapids Dam, are the primary source of eggs for the hatchery. However, hatchery production was supplemented in the early 1980s with eggs from the Bonneville Hatchery. The number of returning adults has been sufficiently high since 1985 so that significant numbers of excess eggs and fry have been available for transfer to Bonneville, Klickitat, and other hatchery facilities. Production goals are expected to be maintained near present level (M.B. Dell, Grant County PUD, personal communication).

To minimize competition with naturally produced salmon, Priest Rapids Hatchery fish are released after most of the naturally produced fish have migrated downstream. Peak abundance of the naturally produced fall chinook salmon occurs in mid-May, and most of these fish migrate out of the Hanford Reach by the end of June (Page et al. 1982). The hatchery fish, released in mid- to late-June are larger than the few naturally produced fish remaining in the Hanford Reach (Dauble et. al. 1984).

Chapman et. al. (1983) estimated the returning adult population to the Hanford Reach in 19X0-1982 accounted for 14 to 26% of hatchery fish. The proportion of hatchery fish above Vernita Bridge (mainly Vernita Bar) was estimated to range from 18 to 33% over the same 3 years. However, numbers of fish released from the Priest Rapids hatchery have doubled since these studies. Thus, relative contribution of hatchery fish to the runs may now be higher.

5.4 SMOLT SURVIVAL DURING REARING AND OUTMIGRATION PERIOD

5.4.1 Past Effects of Hanford Operations

Historical energy-development activities (i.e., production of nuclear materials for weapons production) at Hanford that potentially impacted fall chinook salmon survival included the release of heat, chemicals, and radionuclides through the discharge of reactor cooling water to the river, as and impingement and/or entrainment of fish at reactor cooling water intake structures. The potential for each of these impacts has changed since salmon spawning surveys were initiated in 1948. For example, single-purpose plutonium-production reactors discharged heat and radionuclides into the Columbia River between 1944 and 1971. The marked rise in numbers of salmon redds during 1965 to 1969 was not considered related to the decrease in the number of reactors operating during that period, but to other factors, such as displacement of fish from other mainstem spawning areas (Watson 1970). Paulik (1970) conducted a detailed analysis of fall chinook salmon redd counts and concluded that dam construction was probably the critical factor controlling the number of fall chinook salmon spawning in the Hanford Reach from 1947 to 1969.

More recently, Becker (1985) reviewed potential impacts to salmonids from reactor operations and found no evidence of adverse effects to fall chinook salmon from radioactive materials.

Major spawning areas between river km 585 and 605 were subjected to incompletely mixed reactor effluents for several years. Salmon spawning was sometimes noted within 100 m of the outfall (Watson 1970). However, because the heated effluents rose toward the river surface, influence on eggs and embryos that develop in the bottom substrate was reduced. The general distribution of fall chinook salmon redds did not change following closure of reactors located immediately upstream from major spawning areas (Watson 1970). Additionally, thermal discharges from reactors had no effect on the upstream migration of chinook salmon adults or on the downstream passage of juveniles (Templeton and Countant 1971). The N-Reactor was the only reactor discharging heated effluent to the Hanford Reach after 1971. The closest known spawning ground was located about 5 km downstream of the discharge port, and maximum temperature increases there were estimated at $<0.3^{\circ}\text{C}$ or insufficient to affect embryo survival (DOE 1988). Avoidance behavior may have also reduced the potential for juvenile salmon to be exposed to lethal temperatures from thermal plumes at the point of discharge (Gray et al. 1977). The N-Reactor has not operated since 1987 and is currently in "dry layup" status.

Juvenile (O-age) chinook salmon were found to be impinged on the traveling screens or entrained in the intake system of the Hanford Generating Project (HGP) in the 1970s (Gray et al. 1975). However, a series of improvements, including reductions of screen sizes from 6 to 3 mm (1/4- to 1/8-in.) mesh and a continuous screen wash with a fish return reduced these losses to negligible levels (Page et al. 1977). Fish impingement and traveling screen passage was studied at the adjacent N-Reactor water intake system in 1977. Entrainment was not considered a problem because of the small screen size (1/8-in. mesh). Mortalities to O-age fall chinook salmon fry were estimated to represent $<0.001\%$ of the population.

5.4.2 Current Effects of Hanford Activities

At present, the only thermal discharge to the Hanford Reach occurs at the Washington Nuclear Power Plant (WNP-2) outfall at river km 566. Thermal discharges to the river are from the cold leg of the recirculating cooling water system, and maximum discharge temperatures are about 29°C (84°F). (NRC 1981). However, no evidence exists that downstream migrating salmonids encountering the WNP-2 plume would be exposed to lethal conditions (WPPSS 1985). The intake screen at WNP-2 is located at mid-channel and is sufficiently small that potential for entrainment and/or impingement of juvenile salmonids is negligible.

Indirect releases of radionuclides and chemical constituents to the Columbia River occur as a result of current and past waste disposal practices, and movement of mobile elements is monitored by onsite DOE contractors. Radiological and chemical monitoring results indicate that some contaminants were elevated in groundwater near operating areas (Jaquish and Bryce 1989). For example, concentrations of 90 in the 100-N and 200-East Areas exceeded Environmental Protection Agency's (EPA) drinking water standards in 1988. Tritium continued to move slowly with the general groundwater flow and discharge to the Columbia River. However, dilution by the Columbia River reduces the concentration of radionuclides, and amounts of low-level radioactivity measured in the Columbia River were well below drinking water standards established by the State of Washington and EPA (Jaquish and Bryce 1989).

5.4.3 Effects of Downstream Dams

Juvenile fall chinook salmon from the Hanford Reach must pass four hydroelectric dams before they reach the Columbia River estuary. Potential impacts to smolts during downstream migration that decrease survival and/or potential for adult return are well documented and include delayed migration, predation from birds and resident fish, direct and indirect mortality during turbine passage, and losses from disease and exposure to excess levels of atmospheric gas (reviewed in Collins et al. 1975; Raymond 1979). The main cause for historical decline of salmon populations in the Columbia River Basin has been mortality of juveniles migrating downstream through dams and impoundments (Raymond 1988). Potential mortality is related to flows during migration, i.e., lower flows result in increased passage through turbines and added delay in passage through reservoirs. For example, mortality of salmon smolts was estimated at 45% for each project (dam plus reservoir) during low flow years of 1973 and 1977, compared to 15% mortality per project during the higher runoff and spill in 1978 (Raymond 1988). Species-specific differences in run timing, behavior, or size at migration may influence potential for survival during downstream migration. For example, juvenile fall chinook salmon may be more susceptible to predation than other salmonids in the Columbia River because they are smaller when they migrate to the ocean (Homer and Bjornn 1979).

Current management strategies for increasing survival of fall chinook salmon smolts (and other juvenile salmonids) include maintaining higher flows during smolt outmigration, installing screens to bypass downstream migrants past turbines, and transporting smolts by barge and/or truck past downstream dams. A major fish bypass and collection facility at McNary Dam collects juvenile fall chinook salmon from June through August. Fish are then transported to below Bonneville Dam for release. Collection and loading for transport stresses juvenile salmon, but this

is not perceived as a problem for fall chinook salmon (Maule et al. 1988). Screening turbine intake screens for other U.S. Army Corps of Engineers dams on the Columbia River is currently being considered.

5.5 COMMERCIAL AND SPORT HARVEST

Although the size of the fall chinook salmon run declined coincidentally with loss of spawning habitat in the mid- and upper Columbia River during the 1950s, abundance of adult fish in the lower tributaries and above Bonneville Dam showed the same relative change in run size. According to Van Hyning (1973), this indicated a common factor, such as an increase in ocean fishing, affected survival. Thus, commercial harvest is a major factor influencing fall chinook abundance in the Columbia River.

The total harvest of adult URB (excluding ocean harvest) increased from a low of 9% of the fall chinook run in 1982 to about 63% of the run in 1988. However, the increased harvest has apparently not reduced escapement totals. Total escapement increased from 50,600 adults in 1981 to 176,900 adults in 1987 (Table 5.3). The commercial in-river harvest (Zone 1-5) removed an average of 14% of the total adult URB run from 1980 to 1986 and the tribal fishery (Zone 6) took about 23% of the total during the same interval. Sport fishermen caught about 3% of the total run and only 7% of the total adult harvest from 1980 to 1988 (Table 4.4). Although the proportion of catch for these three fisheries was different, the average share of the total harvest was similar for each fishery on a year-to-year basis.

Data from the recovery of tagged hatchery chinook salmon were summarized to address basin-wide declines in Columbia River stocks (Chapman et al. 1982). Analysis of data from coded-wire tag recoveries indicated that ocean harvest rates exceeded in-river harvest rates for upper Columbia River fall chinook (Lander 1970). Ocean exploitation rates in the late 1970s ranged from 58 to 73% of the total harvest (Chapman et al. 1982). The Pacific Fisheries Management Council (PFMC 1982) estimated that 86% of the total ocean harvest of URB fall chinook occurred in British Columbia and Alaska. Canadian trollers caught an average of 41% of the upper Columbia River fall chinook from 1970 to 1974 (Beiningen 1976). Before 1987, only salmon released from the Priest Rapids Hatchery were used to monitor URB harvest in mixed fisheries. An estimated 69% of Hanford Reach URB hatchery stocks were recovered in offshore fisheries in Alaska and British Columbia (WDF 1981).

TABLE 5.3. Catch Statistics (thousands of fish) for Adult Upriver Bright Fall Chinook Salmon Entering the Columbia River, 1980-1988 (ODFW/WDF 1989)

| Year | Commercial <u>Harvest</u> | Tribal Harvest | sport Catch | Total Catch | Total <u>Run Size</u> | <u>Escapement</u> |
|------|------------------------------|-------------------|----------------|----------------|--------------------------|-------------------|
| 1980 | 5.1 | 9.0 | 0.9 | 15.0 | 76.8 | 61.8 |
| 1981 | 2.4 | 13.4 | 0.7 | 16.0 | 66.6 | 50.6 |
| 1982 | 4.5 | 2.8 | 0.2 | 7.5 | 79.0 | 71.5 |
| 1983 | 4.3 | 12.2 | 0.7 | 17.2 | 86.0 | 68.8 |
| 1984 | 23.7 | 29.0 | 4.4 | 57.1 | 151.4 | 94.3 |
| 1985 | 34.5 | 54.3 | 9.1 | 97.9 | 195.1 | 97.2 |
| 1986 | 58.9 | 90.1 | 10.8 | 159.8 | 281.5 | 121.7 |
| 1987 | 104.3 | 120.0 | 18.2 | 242.5 | 419.4 | 176.9 |
| 1988 | 79.9 | 119.2 | 16.5 | 215.6 | 339.9 | 124.3 |

No comparable information exists on the relative contribution of naturally spawning URB stocks to the ocean fisheries. However, a multi-agency study was initiated in 1987 to determine the importance of this stock in ocean and Columbia River fisheries. The Washington Department of Fisheries (WDF), the Yakima Indian Nation (YIN), the Columbia River Intertribal Fish Commission (CRIFTC), and the U.S. Fish and Wildlife Service (USFWS) are implanting coded-wire tags in naturally produced juvenile fall chinook. Information from tag recoveries will be used to manage harvest of returning adults and to evaluate potential impacts to the stock from activities in the Columbia Basin (Norman 1987; DeVore 1989).

5.6 OTHER FACTORS AFFECTING ADULT SURVIVAL

Adult salmonids have problems passing hydroelectric dams when migrating upstream to their spawning grounds. Some portion of interdam differences in adult passage counts over ladders has been attributed to “dropback” mortality (Fredd 1966). Adult losses of 20% have been noted at a lower Columbia River Dam (Junge 1980). Differences in counts between dams influence the accuracy of estimates of adult escapement to upstream spawning areas, including estimates for the Hanford Reach. Passage problems and associated mortalities are thought to be usually greater for fall chinook salmon than other races because fall chinook return in later summer and fall when river flows are lower and temperatures are higher (Collins et al. 1962). Average delays in passage for upstream migrating adults ranged from 18 to 216/h for various studies conducted in the Columbia and Snake rivers from 1948 to 1977 (reviewed in Haynes and Gray 1980). The additive effects of extensive passage delays resulting from dropback, milling, and/or greater swimming depths could delay migration timing and ultimately affect spawning success for

fall chinook salmon in the upper Snake River (Haynes and Gray 1980). Other conditions associated with passing fish past barriers may contribute to mortality. For example, crowding associated with fish ladders and elevated temperatures occurring during late summer migration may increase potential for disease transmission from the pathogen Flexibacter columnaris and other infectious diseases (Becker and Fujihara 1978; Homer and Bjorn 1979).

Impacts from pollution point sources or chemicals contained in runoff from irrigation returns are also a consideration. For example, there is evidence that fluoride released from an aluminum plant above John Day Dam impacted passage time and survival of adult salmonids (Damaker and Day 1984, 1985).

6.0 RECOMMENDATIONS FOR FUTURE MANAGEMENT OF FALL CHINOOK SALMON IN THE HANFORD REACH

Care must be taken to protect and enhance the URB stock of fall chinook salmon because the Hanford Reach is the major spawning area for this valuable resource. Widespread habitat destruction in the Columbia River has increased the importance of the Hanford Reach to fall chinook salmon populations in the last 40 years. Runs to the Hanford Reach have increased because hydroelectric development has eliminated most other mainstem spawning areas, natural production has been sustained, and extensive hatchery outplanting has occurred. However, it should not be assumed that runs can be maintained with present management strategies. The status of fall chinook populations needs to be monitored because of potential for changes in water use practices (i.e., irrigation needs, hydroelectric power generation), ocean and in-river harvest, and future development projects that may impact water quality. These and other unforeseen activities may have a major impact on the future survival of fall chinook salmon in the Hanford Reach. The following sections discuss research needs for effective management of fall chinook salmon production in the Columbia River.

* Improve the documentation of current fall chinook salmon spawning areas

Fall chinook salmon spawning areas at Vemita Bar have been described by Chapman et al. (1986), and other sites have been studied by Swan et al. (1988). But these sites are only a portion of the known spawning sites in the Hanford Reach. Additional characterization is needed to accurately evaluate changes in spawning area boundaries and redd abundance resulting from future activities in the Hanford Reach or from changes in present management policies. Locations of spawning areas should be mapped and physical variables described before available spawning habitat and production potential of the Hanford Reach can be further assessed.

Aerial photography can be useful in providing a permanent record of spawning areas. However, the authors and others (Chapman et al. 1983) have found this method less useful for quantitative analysis. Visual inspection of salmon spawning is superior to aerial photography for estimating redds. SCUBA can be used in conjunction with aerial surveys to obtain additional information on redd abundance and location (Swan et al. 1988). Our analysis of photographic techniques indicated that color video was superior to color photographs for documenting location and estimating abundance of salmon redds. Salmon redds that were visible across the entire river channel (depth estimated to 4 m) with video film (and with the naked eye) were not visible in photographic prints. Visual counts of

redds made from aircraft remain superior to estimates of redd numbers made from film. Further development of techniques, including photographic mapping, is needed to obtain a permanent record of salmon spawning locations. Permanent record of locations will provide a means to assess changes as a result of future development activities in the Hanford Reach.

Characterize habitat requirements and determine production potential of fall chinook salmon in the Hanford Reach

Although principal spawning areas in the Hanford Reach have been identified, densities of redds within and between areas are highly variable. Given the range of conditions (i.e., depth, substrate, current velocity) in which fall chinook salmon spawn, it is doubtful that all suitable areas are used. It may be that key factors difficult to measure or not identified also contribute to selection of spawning areas. Studies should be initiated to characterize the physical and hydrologic parameters that influence selection of salmon spawning sites and embryo survival. This information can be used to develop a preliminary habitat suitability model for assessing population change and for evaluating production potential in the Hanford Reach.

Evaluate current supplementation programs

Increased hatchery production may be the only means of maintaining and/or increasing fall chinook salmon production in the mid-Columbia River, particularly if current spawning areas are used at their maximum potential. Present salmon production facilities in the Hanford Reach are funded by a combination of state and federal agencies and public utility districts. Management policies at the Priest Rapids Hatchery are not likely to change in the immediate future, and funds for the Ringold rearing facility have been cut from the federal budget year after year, and the future of this facility depends on maintaining or supplementing the annual budget. Management of naturally produced populations may take on increased importance if hatchery supplementation strategies fail or if run size decreases because of increased commercial and sport harvest and/or other mortality factors. Recent studies with steelhead indicate that wild spawners were more likely to produce surviving subyearlings and smolts than are hatchery smolts (Chilcote et al. 1986). Thus, the genetic integrity of wild populations in the Hanford Reach could be threatened with increased hatchery supplementation or introduction of stocks from other basins. Evaluation of current hatchery programs is ongoing (Norman 1987), and this information needs to be considered in resource planning by state and federal agencies and tribes. Additionally,

fisheries management policies influencing hatchery production and regulation of commercial and tribal fisheries must be factored into the assessment of the relative importance of the Hanford Reach to fall chinook salmon populations.

* Maintain flow policies designed to protect all life stages of fall chinook salmon

Results from extensive field and laboratory studies conducted to date (Parametrix et al. 1979; Chapman et al. 1983; Weitkamp et al. 1982; Neitzel et al. 1984) characterized salmon spawning on Vernita Bar in relation to flow patterns and assessed the effect of various flows on eggs and alevins. A long-term (1998 to 2005) Vernita Bar Settlement Agreement was approved by a Federal Energy Regulatory Commission (FERC) order in December 1988 that established obligations and procedures to protect fall chinook salmon at Vernita Bar. Activities include monitoring redd construction and maturation from egg to emergent fry and providing adequate flows during spawning and egg incubation (Carlson and Dell 1989). It is important that agencies and utilities continue to cooperate in establishing flow regimes that protect fall chinook salmon in the Hanford Reach. These flow regimes need to consider the entire life cycle of fall chinook salmon, from spawning to outmigration.

- Ensure adequate protection of the Hanford Reach against current activities and future development activities

Regulatory aspects and Northwest politics will continue to influence the management of fall chinook salmon in the Hanford Reach. The Hanford Reach is currently under study by the National Park Service and the U.S. Fish and Wildlife Service to determine if it should be protected under the Wild and Scenic River designation or some other status. A moratorium on development was initiated in November 1988 and will protect the Hanford Reach for up to 8 years (U.S. House of Representatives, H.R. 3614). Two past development activities have potentially jeopardized the fall chinook salmon population. For example, the Army Corps of Engineers proposed to construct Ben Franklin Dam near river km 563 in the late 1970s. Such a structure would have eliminated most of the salmon spawning areas in the Hanford Reach (Fickeisen et al. 1980). Another plan recently considered was construction of a shallow-draft navigation channel through the Hanford Reach. This project could severely impact fall chinook salmon by reducing available spawning habitat, increasing sedimentation, and increasing mortality from barge activity and changes in flows.

Operation of hydroelectric facilities for irrigation needs and power production will continue to have a major impact on the survival of fall chinook salmon. Adequate controls on

upstream industries, including irrigation practices, that alter the use and quality of the Columbia River are also needed. For example, the continuing erosion of some high bank areas in the Hanford Reach produces high loads of silt. The instability of banks (e.g., the White Bluffs near river km 595) is due, in part, to discharge of irrigation waste water on land to the north and east of the river. Possible impacts of the increased siltation on salmon spawning and the potential for change in channel morphology and flows because of bank slumping need to be recognized.

- Develop methods to predict potential exposure scenarios for redds downstream of contaminants originating from waste storage

Following the shut-down of N-Reactor in 1987, emphasis at Hanford has shifted from nuclear fuel production to cleanup of existing waste sites. A Tri-Party Agreement was established between the U.S. Department of Energy, the State of Washington, and the U.S. Environmental Protection Agency mandating cleanup of existing nuclear waste sites at Hanford (WSDE et al. 1989). The long-term effects (if any) on fall chinook salmon of nuclear waste materials that migrate from present storage sites and enter the Columbia River are unknown. Methods are not yet available to predict potential exposure scenarios for fall chinook salmon embryos developing in redds downstream of contaminants originating from hazardous waste storage. However, future groundwater transport models and site characterization efforts should evaluate the potential for contaminants to intersect major spawning areas.

It is evident that issues surrounding the status of fall chinook salmon populations in the Hanford Reach are complex. However, resources agencies should not consider activities within the Hanford Reach as the controlling variable for fall chinook salmon production in the Columbia River system. Rather these populations should be viewed as an important contribution. A holistic approach to management of fall chinook salmon would include the development and maintenance of suitable spawning and rearing habitat in other areas of the Columbia River drainage.

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APPENDIX A

SUMMARY OF REDD COUNTS

TABLE A.1. Summary of Redd Counts by Area, 1948-1988. The highest count for individual areas were summed to obtain the peak redd counts (shown in Table 3.2)

| year | Date | | Location | | | | | | | | | | Other | Total |
|------|-----------|------|----------|---|-----|----|-----|---|----|----|-----|-----|-------|-------|
| | | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | | |
| 194x | Nov 8 | Mon | 120 | 330 | 0 | 38 | 69 | X3 | 90 | 2 | 0 | 53 | 2 | 787 |
| 1949 | Oct 18 | Tues | 1 | 5 | 0 | 0 | 19 | 5 | 5 | 0 | 1 | 1 | 3 | 39 |
| | O c t 2 6 | Wed | 45 | 51 | 0 | 9 | 156 | 26 | 13 | 6 | 0 | 0 | 6 | 313 |
| | Nov 16 | Wed | 35 | 44 | 0 | 0 | 105 | 19 | 0 | 6 | | 0 | 0 | 215 |
| 1950 | Oct 26 | Tues | 24 | 30 | 0 | 36 | 72 | 58 | 14 | 0 | 2 | 44 | 0 | 2x0 |
| | Nov 10 | Fri | 21 | 35 | 0 | 30 | 74 | 39 | 13 | 9 | 3 | 41 | 0 | 265 |
| 1951 | Oct 16 | Tues | 0 | 0 | 3 | 0 | 0 | Survey terminated between 100-H and 100D acres--poor visibility | | | | | 1 | 4 |
| | O c t 2 6 | Fri | 0 | 3 | 0 | 24 | 43 | 32 | 0 | 2 | 5 | 45 | 2 | 206 |
| | Nov 7 | Wed | 5 | 7 | 0 | 45 | 90 | 38 | 21 | 0 | 0 | 91 | 0 | 297 |
| 1952 | Oct 17 | Fri | 0 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 2 | 0 | 4 |
| | O c t 2 3 | Thur | 73 | Records for redd location/number are lost for Ringold to 100-D Area | | | | | | | --- | 21 | 38 | 311 |
| | Nov 5 | Wed | 66 | | | | | | | | 23 | 40 | 3 | 528 |
| | Nov 21 | Fri | 29 | | | | | | | | 5 | 7 | 1 | 133 |
| 1953 | Oct 16 | Fri | 0 | 0 | 0 | 0 | 5 | 0 | 0 | 0 | 0 | 11 | 0 | 16 |
| | O c t 2 2 | Thur | 0 | 0 | 0 | 0 | 14 | 0 | 0 | 0 | 0 | 51 | 0 | 68 |
| | Nov 5 | Thur | 0 | 2 | 0 | 6 | 38 | 0 | 0 | 0 | 0 | 83 | 0 | 139 |
| | Nov 24 | Tues | 7 | 5 | 0 | 10 | 40 | 0 | 0 | 0 | 0 | 53 | 0 | 115 |
| 1954 | Oct 14 | Thur | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | Oct 25 | Mon | 0 | 5 | 0 | 0 | 54 | 34 | 1 | 0 | 7 | 6 | 0 | 107 |
| | Nov 2 | Tues | 4 | 12 | 0 | 8 | 83 | 44 | 0 | 0 | 5 | 4 | 0 | 160 |
| 1955 | Oct 13 | Thur | 0 | 1 | 0 | 0 | 10 | 0 | 0 | 0 | 0 | 1 | 0 | 12 |
| | Oct 28 | Fri | 0 | 0 | 0 | 0 | 33 | 10 | 1 | 1 | 0 | 1 | 0 | 46 |
| | Nov 14 | Mon | 0 | 11 | 0 | 0 | 34 | 12 | 0 | 0 | 0 | 3 | 0 | 60 |
| 1956 | Oct 22 | Mo | 0 | 0 | 0 | 2 | 16 | 14 | 0 | 4 | 0 | 9 | 0 | 45 |
| | Nov 2 | Fri | 0 | 0 | 0 | 7 | 40 | 16 | 0 | 6 | 0 | 17 | 0 | 86 |
| | Nov 16 | Fri | 0 | 3 | 0 | 1 | 34 | 17 | 0 | 5 | 0 | 15 | 0 | 75 |
| 1957 | Oct 11 | Fri | 17 | | 15 | 1 | 0 | 0 | 0 | 0 | 42 | 32 | 1 | 109 |
| | Oct 24 | Thur | 1 | 6: | 1 | 15 | 74 | 34 | 12 | 1 | 1 | 0 | 0 | 206 |
| | Oct 29 | Tues | 8 | 87 | 1 | 39 | 170 | 30 | 90 | 0 | 0 | 100 | 0 | 525 |
| | Nov 6 | Wed | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 |
| 1958 | Oct 13 | Mon | 32 | 5 | 100 | 1 | 2X | 2 | 6 | 1 | 130 | 81 | 2 | 388 |
| | Oct 20 | Mon | 3 | 0 | 7 | 7 | 8 | 3 | 1 | 0 | 6 | 0 | 0 | 35 |
| | Oct 27 | Mon | 0 | 87 | 0 | 99 | 223 | 45 | 64 | 48 | 56 | 176 | 0 | 79x |
| | Nov 3 | Mon | 15 | 27 | 0 | 26 | 97 | 25 | 0 | 17 | 0 | 2 | 0 | 209 |
| | Nov 10 | Mon | 0 | 8 | 14 | 0 | 0 | 0 | 17 | 15 | 0 | 0 | 0 | 54 |
| | Nov 17 | Mon | 0 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 2 |
| 1959 | Oct 13 | Tues | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 6 | 0 | 7 |
| | Oct 27 | Tues | 0 | 0 | 0 | 8 | 10 | 5 | 0 | 0 | 1 | 30 | 0 | 54 |
| | Nov 10 | Tues | 1 | 0 | 0 | 36 | 60 | 40 | 1 | 0 | 32 | 111 | 0 | 281 |

TABLE A.1. (contd)

| Year | Date | | Location | | | | | | | | | | | Total |
|------|--------|------|----------|-----|-----|-----|-----|-----|-----|----|-----|------|-------|-------|
| | | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | Other | |
| 1960 | Sep 28 | Wed | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 24 | 16 | 0 | 40 |
| | Oct 18 | Tues | 0 | 0 | 16 | 14 | 0 | 2 | 2 | 0 | 34 | 61 | 0 | 129 |
| | Nov 10 | Thur | 0 | 0 | 31 | 19 | 67 | 23 | 9 | 0 | 19 | 90 | 0 | 258 |
| 1961 | Nov 6 | Sat | 0 | 15 | 12 | 19 | 82 | 46 | 7 | 4 | 23 | 160 | 0 | 368 |
| | Nov 13 | Fri | 0 | 0 | 0 | 49 | 86 | 45 | 6 | 0 | 2 | 640 | 0 | 828 |
| 1962 | Oct 15 | Mon | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 43 | 0 | 45 |
| | Oct 22 | Mon | 2 | 13 | 16 | 11 | 11 | 2 | 0 | 0 | 1 | 56 | 0 | 112 |
| | Nov 1 | Thur | 4 | 66 | 80 | 48 | 151 | 98 | 83 | 0 | 0 | 310 | 0 | 840 |
| | Nov 9 | Fri | 4 | 60 | 120 | 66 | 262 | 83 | 88 | 1 | 0 | 367 | 0 | 1051 |
| | Nov 21 | Wed | 5 | 75 | 33 | 0 | 83 | 22 | 13 | 0 | 0 | 405 | 0 | 636 |
| 1963 | Oct 8 | Tues | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 0 | 3 |
| | Oct 18 | Fri | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 1 | 0 | 54 | 0 | 57 |
| | Oct 28 | Mon | 0 | 29 | 56 | 40 | 75 | 13 | 38 | 1 | 9 | 178 | 0 | 439 |
| | Nov 5 | Tues | 0 | 73 | 102 | 112 | 187 | 24 | 84 | 3 | 13 | 346 | 0 | 944 |
| | Nov 12 | Tues | 0 | 122 | 159 | 116 | 345 | 56 | 100 | 2 | 12 | 342 | 0 | 1254 |
| | Nov 21 | Thur | 0 | 90 | 113 | 54 | 209 | 53 | 90 | 2 | 8 | 284 | 0 | 903 |
| 1964 | Oct 21 | Wed | 0 | 0 | 13 | 5 | 20 | 1 | 21 | 2 | 16 | 102 | 0 | 180 |
| | Oct 30 | Fri | 0 | 29 | 94 | 110 | 226 | 90 | 110 | 26 | 36 | 300 | 0 | 1021 |
| | Nov 16 | Mon | 5 | 55 | 70 | 91 | 245 | 99 | 119 | 12 | 24 | 624 | 0 | 1339 |
| 1965 | Oct 21 | Wed | 0 | 0 | 10 | 3 | 13 | 1 | 12 | 1 | 3 | 58 | 0 | 101 |
| | Oct 29 | Fri | 3 | 73 | 75 | 47 | 231 | 30 | 99 | 10 | 154 | 497 | 3 | 1122 |
| | Nov 11 | Thur | 4 | 136 | 123 | 202 | 345 | 37 | 112 | 11 | 130 | NS* | 3 | 1003 |
| | Nov 16 | Tues | 3 | 117 | 111 | 138 | 298 | 50 | 96 | 8 | 24 | 652 | 3 | 1477 |
| 1966 | Oct 6 | Thru | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 |
| | Oct 21 | Fri | 1 | 8 | 8 | 0 | 9 | 0 | 7 | 1 | 2 | 44 | 0 | 80 |
| | Oct 26 | Wed | 10 | 36 | 30 | 46 | 59 | 27 | 42 | 2 | 0 | 284 | 0 | 536 |
| | Nov 2 | Wed | 8 | 132 | 120 | 267 | 459 | 230 | 270 | 1 | 37 | 1300 | 0 | 2824 |
| | Nov 9 | Wed | 9 | 113 | 140 | 263 | 697 | 160 | 220 | 0 | 4 | 1085 | 0 | 2691 |
| | Nov 23 | Wed | 1 | 64 | 70 | 78 | 197 | 35 | 54 | 0 | 1 | 420 | 0 | 920 |
| 1967 | Sep 28 | Thur | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | Oct 16 | Mon | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | Oct 26 | Thur | 0 | 5 | 4 | 6 | 13 | 8 | 35 | 0 | 4 | 348 | 1 | 424 |
| | Nov 2 | Thur | 24 | 148 | 77 | 207 | 342 | 110 | 162 | 8 | 15 | 775 | 0 | 1868 |
| | Nov 8 | Wed | 21 | 180 | 160 | 248 | 499 | 155 | 244 | 28 | 6 | 1340 | 0 | 2881 |
| | Nov 15 | Wed | 34 | 205 | 160 | 182 | 458 | 150 | 455 | 23 | 17 | 660 | 0 | 2344 |
| | Nov 22 | Wed | 15 | 124 | 115 | 209 | 480 | 110 | 307 | 20 | 4 | 780 | 1 | 2165 |
| 1968 | Oct 2 | Wed | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 |
| | Oct 14 | Mon | 0 | 10 | 0 | 5 | 0 | 0 | 0 | 0 | 0 | 25 | 0 | 25 |
| | Oct 21 | Mon | 24 | 46 | 61 | 51 | 44 | 16 | 31 | 0 | 1 | 0 | 0 | 274 |
| | Oct 29 | Tues | 79 | 183 | 300 | 186 | 355 | 135 | 182 | 19 | 35 | 1500 | 0 | 2974 |
| | Nov 6 | Wed | 130 | 250 | 300 | 169 | 437 | 107 | 138 | 14 | 50 | 910 | 0 | 2505 |
| | Nov 15 | Fri | 111 | 214 | 320 | 134 | 742 | 79 | 162 | 14 | 52 | 1400 | 5 | 3233 |

TABLE A.1. (contd)

| Year | Date | | Location | | | | | | | | | | Other | Total |
|------|--------|-------|----------|-----|-----|-------|---------------------------------|-----|-----|-------|-----|------|-------|-------|
| | | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | | |
| 1969 | Oct 13 | Mon | 11 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 11 |
| | Oct 21 | Tues | 7 | 16 | 12 | 4 | 15 | 0 | 10 | 1 | 0 | 80 | 0 | 145 |
| | Oct 30 | Thu | 82 | 155 | 190 | 245 | 246 | 60 | 106 | 6 | 32 | 710 | 4 | 1836 |
| | Nov 6 | Thur | 145 | 401 | 410 | 427 | 903 | 126 | 362 | 30 | 50 | 1034 | 0 | 3888 |
| | Nov 11 | Mon | 252 | 189 | 220 | 309 | 365 | 97 | 180 | 26 | 14 | 1011 | 0 | 2663 |
| | Nov 23 | Sun | 175 | 221 | 210 | 375 | 762 | 111 | 260 | NS(a) | NS | 1075 | 0 | 3189 |
| 1970 | Oct 8 | Thur | 14 | 1 | 10 | 0 | 0 | 0 | 0 | 0 | 2 | 39 | 3 | 69 |
| | Oct 15 | Thurs | 22 | 6 | 16 | 0 | 1 | 0 | 0 | 0 | 0 | 66 | 6 | 117 |
| | Oct 22 | Thur | 13 | 20 | 41 | 22 | 27 | 20 | 26 | 2 | 2 | 130 | 6 | 309 |
| | Oct 28 | Wed | 21 | 244 | 230 | 237 | 322 | 63 | 125 | 0 | 72 | 980 | 9 | 2303 |
| | Nov 5 | Thur | 74 | 360 | 215 | 302 | 541 | 152 | 228 | 0 | 34 | 1428 | 2 | 3336 |
| | Nov 12 | Thu | 90 | 367 | 210 | 277 | 746 | 159 | 259 | 0 | 43 | 1486 | 6 | 3643 |
| | Nov 19 | Thur | 65 | 195 | 150 | 239 | 566 | 99 | 209 | 0 | 17 | 1094 | 0 | 2634 |
| 1971 | Oct 18 | Mon | 21 | 10 | 2 | 7 | 6 | | 10 | 0 | 0 | 41 | 3 | 91 |
| | Oct 28 | Thur | 44 | 108 | 47 | 32 | 86 | 22 | 48 | 0 | 1 | 310 | 0 | 698 |
| | Nov 4 | Thur | 156 | 308 | 160 | 370 | 659 | 72 | 130 | 12 | 9 | 1120 | 0 | 2996 |
| | Nov 16 | Tues | 183 | 374 | 180 | 386 | 740 | 32 | 230 | 24 | 10 | 1361 | 0 | 3504 |
| 1972 | Oct 13 | Fri | 4 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 5 |
| | Oct 24 | Tues | 6 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 6 |
| | Nov 6 | Mon | 71 | 78 | 67 | 120 | 109 | 23 | 74 | 0 | 0 | 96 | 0 | 638 |
| | Nov 14 | Tues | 77 | 66 | 54 | 59 | 110 | 52 | 69 | 0 | 4 | 127 | 0 | 618 |
| | Nov 27 | Mon | 71 | 131 | 103 | 131 | 88 | 42 | 33 | 0 | 0 | 61 | 0 | 660 |
| 1973 | Oct 15 | Mon | 121 | 40 | 7 | 0 | 26 | 6 | 37 | 0 | 9 | 110 | 5 | 361 |
| | Oct 26 | Fri | 55 | 108 | 32 | 73 | 151 | 55 | 95 | 2 | 59 | 429 | 3 | 1062 |
| | Nov 2 | Fri | 44 | 86 | 40 | 114 | 288 | 82 | 144 | 3 | 59 | 599 | 4 | 1463 |
| | Nov 13 | Tues | 43 | 330 | 123 | 170 | 722 | 176 | 283 | 7 | 29 | 882 | 1 | 2766 |
| 1974 | Oct 15 | Tues | 76 | 11 | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 13 | 3 | 105 |
| | Oct 24 | Thur | 54 | 13 | 11 | 4 | 8 | 9 | 8 | 0 | 0 | 30 | 2 | 139 |
| | Nov 5 | Tues | 35 | 44 | 0 | 1 | 16 | 34 | 25 | 0 | 1 | 153 | 0 | 309 |
| | Nov 15 | Fri | 61 | 74 | 12 | 12 | 86 | 13 | 67 | 0 | 0 | 76 | 0 | 401 |
| | Nov 26 | Tues | 59 | 113 | 28 | 49 | 72 | 47 | 62 | 0 | 4 | 142 | 0 | 576 |
| 1975 | Oct 16 | Thur | 68 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 37 | 0 | 107 |
| | Oct 24 | Wed | 62 | 263 | 140 | 256 | 373 | 50 | 215 | 30 | 46 | 427 | 1 | 1863 |
| | Nov 1 | Fri | 7 | 261 | 120 | 261 | 359 | 79 | 151 | 52 | NS | NS | 0 | 1290 |
| | Nov 19 | Wed | 2 | 19 | 0 | ----- | -Survey Terminated Due to Fog-- | | | | | | 0 | 21 |
| | Nov 20 | Thur | 0 | 146 | 54 | 21 | 218 | 13 | 124 | 0 | 86 | 995 | 0 | 1657 |
| 1976 | Oct 12 | Tues | 15 | 0 | 0 | 6 | 0 | 0 | 0 | 0 | 0 | 5 | 0 | 26 |
| | Oct 26 | Tues | 17 | 110 | 106 | 84 | 367 | 79 | 110 | 7 | 105 | 320 | 0 | 1305 |
| | Nov 5 | Fri | 2 | 137 | 140 | 185 | 384 | 105 | 135 | 6 | 182 | 599 | 0 | 1875 |
| | Nov 15 | Mon | 2 | 162 | 102 | 158 | 356 | 76 | 140 | 2 | 123 | 487 | 0 | 1608 |

TABLE A. 1. (contd)

| Year | Date | | Location | | | | | | | | | | Other | Total |
|------|--------|------|----------|-----|--|------|------|-------------------------------|-----|-----|-----|------|-------|-------|
| | | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | | |
| 1977 | Oct 13 | Thu | 7 | 12 | 0 | 1 | 2 | 8 | 0 | 0 | 6 | 6 | 0 | 42 |
| | Oct 24 | Mon | 5 | 104 | 64 | 118 | 234 | 44 | 77 | 2 | 29 | 242 | 0 | 919 |
| | Oct 31 | Mon | 6 | 268 | 110 | 265 | 519 | 58 | 209 | 4 | 47 | 215 | 0 | 1701 |
| | Nov 7 | Mon | 2 | 198 | -----Survey discontinued--High winds and dust----- | | | | | | | | | 200 |
| | Nov 10 | Thur | 2 | 291 | 140 | 355 | 1136 | 161 | 263 | 8 | 37 | 760 | 0 | 3153 |
| | Nov 17 | Thur | 0 | 205 | 110 | 347 | 1013 | 99 | 169 | 4 | 23 | 145 | 0 | 2115 |
| 1978 | Oct 9 | Mon | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | Oct 16 | Mon | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | Oct 26 | Thur | 0 | 33 | 13 | 5 | 41 | 4 | 31 | 0 | 5 | 50 | 0 | 182 |
| | Nov 6 | Mon | 18 | 71 | 38 | 19 | 53 | 2 | 90 | 0 | 20 | 20 | 0 | 331 |
| | Nov 11 | Sat | 0 | 156 | 60 | 326 | 789 | 74 | 386 | 73 | 145 | 975 | 0 | 2984 |
| 1979 | Oct 7 | Sun | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 2 |
| | Oct 27 | Sat | 9 | 73 | 27 | 97 | 170 | 28 | X7 | 8 | 13 | 176 | 0 | 688 |
| | Nov 3 | Sat | 25 | 214 | 105 | 297 | 672 | 172 | 257 | 42 | 92 | 980 | 0 | 2856 |
| | Nov 20 | Tues | 66 | 229 | 145 | 240 | 67 | Survey interrupted--Dense fog | | --- | | 142 | 0 | 889 |
| 1980 | Oct 16 | Thur | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | Oct 24 | Fri | 2 | 19 | 7 | 5 | 13 | 8 | 8 | 0 | 0 | 18 | 0 | 80 |
| | Nov 4 | Tues | 29 | 112 | 32 | 64 | 194 | 33 | 119 | 0 | 35 | 856 | 0 | 1474 |
| | Nov 13 | Thur | 18 | 102 | 0 | 0 | 53 | 5 | 87 | 0 | 0 | 288 | 0 | 553 |
| 1981 | Oct 17 | Sat | 8 | 3 | 3 | 2 | 19 | 0 | 13 | 0 | 11 | 76 | 0 | 135 |
| | Oct 24 | Sat | 45 | 113 | 47 | 38 | 390 | 70 | 222 | 26 | 55 | 736 | 0 | 1742 |
| | Nov 4 | Wed | 82 | 222 | 163 | 215 | 809 | 118 | 323 | 58 | 62 | 343 | 0 | 2395 |
| | Nov 8 | Sun | 31 | 173 | 190 | 270 | 1103 | 151 | 553 | 38 | 80 | 2120 | 0 | 4709 |
| 1982 | Oct 19 | Tues | 0 | 9 | 0 | 1 | 2 | 2 | 12 | 0 | 3 | 0 | 0 | 24 |
| | Oct 24 | Sun | 0 | 29 | 17 | 15 | 163 | 36 | 102 | 8 | 71 | 542 | 0 | 1383 |
| | Oct 31 | Sun | 0 | 85 | 83 | 129 | 561 | 93 | 352 | 31 | 100 | 1970 | 6 | 3404 |
| | Nov 7 | Sun | 5 | 149 | 170 | 232 | 1102 | 160 | 560 | 32 | 149 | 2060 | 12 | 4631 |
| | Nov 20 | Sat | 7 | 146 | 210 | 278 | 852 | 119 | 450 | 79 | 113 | 1523 | 16 | 3193 |
| 19x3 | Oct 16 | Sun | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 13 | 0 | 14 |
| | Oct 23 | Sun | 0 | 11 | 10 | 7 | 32 | 14 | 23 | 5 | 13 | 196 | 0 | 311 |
| | Nov 1 | Tues | 11 | 100 | 77 | 236 | 657 | 75 | 291 | 28 | 35 | 1020 | 0 | 2530 |
| | Nov 8 | Tues | 5 | 284 | 160 | 425 | 1122 | 140 | 407 | 16 | 21 | 1090 | 0 | 3670 |
| | Nov 12 | Sat | 24 | 233 | 200 | 511 | 1310 | 198 | 453 | 33 | 43 | 2216 | 0 | 5221 |
| 1984 | Oct 17 | Wed | 0 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 0 | 6 |
| | Oct 21 | Sun | 0 | 1 | 0 | 0 | 8 | 1 | 10 | 0 | 0 | 153 | 0 | 173 |
| | Oct 27 | Sat | 0 | 102 | 47 | 352 | 599 | 47 | 299 | 14 | 55 | 1537 | 3 | 2995 |
| | Nov 5 | Mon | 81 | 379 | 90 | 950 | 1430 | 57 | 853 | 87 | 33 | 1080 | 0 | 5040 |
| | Nov 11 | Sun | RR | 514 | 190 | 1052 | 1920 | 53 | 835 | 85 | 27 | 2314 | 0 | 7078 |
| | Nov 18 | Sun | 27 | 384 | 90 | 635 | 1108 | 85 | 542 | 84 | 21 | 1374 | 7 | 4351 |
| 1985 | Oct 20 | Sun | 0 | 18 | 0 | 12 | 37 | | 12 | 2 | 0 | 399 | 1 | 482 |
| | Oct 26 | Sat | 0 | 51 | 5 | 130 | 298 | 3: | 107 | 13 | 37 | 595 | 4 | 1277 |
| | Nov 3 | Sun | 12 | 624 | 250 | 770 | 1949 | 370 | X63 | 152 | 107 | 2411 | 15 | 7523 |
| | Nov Y | Sat | 0 | 314 | 42 | 334 | 1030 | 91 | 5x9 | 151 | 60 | 2047 | 11 | 4669 |

TABLE A. 1. (contd)

| Year | Date | | Location | | | | | | | | | | Other | Total |
|------|--------|------|----------|-----|-----|-----|---|-----|------|-----|-----|------|-------|-------|
| | | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | | |
| 1986 | Oct 8 | Wed | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | Oct 19 | Sun | 0 | 0 | 2 | 1 | 0 | 2 | 3 | 0 | 0 | 28 | 1 | 37 |
| | Oct 25 | Sat | 1 | 14 | 11 | 26 | 77 | 13 | 65 | II | 4 | 305 | 1 | 528 |
| | Nov 1 | Sat | 14 | 312 | 120 | 308 | 872 | 127 | 598 | 119 | 32 | 1640 | 16 | 4158 |
| | Nov 8 | Sat | 10 | 490 | 250 | 656 | 1740 | 370 | 1074 | 199 | 51 | 2635 | 17 | 7492 |
| | Nov 15 | sat | 14 | 321 | 180 | 672 | 1810 | 190 | 1020 | 213 | 73 | 3082 | 14 | 7589 |
| | Nov 22 | Sat | 11 | 325 | 200 | 515 | 1440 | 168 | 799 | 201 | 49 | 2768 | 22 | 6498 |
| 1987 | Oct 17 | Sat | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 6 |
| | Oct 24 | Sat | 3 | 0 | 0 | 2 | 2 | 0 | 21 | 1 | 5 | 21 | 0 | 55 |
| | Oct 31 | Sat | 19 | 95 | 44 | 161 | 332 | 60 | 135 | 49 | 32 | 678 | 15 | 1620 |
| | Nov 7 | Sat | 75 | 463 | 150 | 709 | 1626 | 86 | 709 | 132 | 74 | 2086 | 27 | 6137 |
| | Nov 15 | Sun | 183 | 780 | 320 | 900 | 1870 | 90 | 951 | 117 | 37 | 2613 | 25 | 7886 |
| | Noc 22 | Sun | 251 | 402 | 150 | 499 | 1372 | 95 | 600 | 142 | 50 | 3150 | 22 | 6733 |
| 1988 | Oct 17 | Mon | 0 | 6 | 0 | 1 | 0 | 0 | 5 | 0 | 0 | 9 | 2 | 23 |
| | Oct 22 | Sat | 0 | 4 | 0 | 2 | 7 | 5 | 5 | 0 | 0 | 50 | 0 | 73 |
| | Oct 29 | sat | 6 | 156 | 80 | 147 | 411 | 71 | 243 | 43 | 63 | 877 | 21 | 2118 |
| | Nov 5 | Sun | 160 | 555 | 190 | 679 | 1680 | 310 | 870 | 202 | 123 | 2742 | 48 | 7559 |
| | Nov 14 | Tues | 264 | 715 | 350 | 828 | 1550 | 220 | 743 | 184 | 112 | 2213 | 42 | 7221 |
| | Nov 20 | MO" | 6 | 217 | 0 | 250 | Survey discontinued--High winds and river level | | | | | | | 473 |

(a) US = Not surveyed,

TABLE A.? Estimated Number of Redds for the Lower
Ynkima River (river km to Richland)

| Year | <u>Peak Count</u> |
|------|-------------------|
| 1960 | 0 |
| 1961 | 29 |
| 1962 | 5 |
| 1963 | 108 |
| 1964 | 40 |
| 1965 | 66 |
| 1966 | 135 |
| 1967 | 177 |
| 1968 | 62 |
| 1969 | 829 |
| 1970 | 634 |
| 1971 | 88 |
| 1972 | 136 |
| 1973 | 174 |
| 1974 | 131 |
| 1975 | 339 |
| 1976 | 240 |
| 1977 | 82 |
| 1978 | 32 |
| 1979 | 0 |
| 1980 | 11 |
| 1981 | 12 |
| 1982 | |
| 1983 | 50 |
| 1984 | 118 |
| 1985 | 45 |
| 1986 | 134 |
| 1987 | 14 |
| 1988 | 8 |

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